MANAGING THE NATIONAL WILDLIFE REFUGE SYSTEM WITH CLIMATE CHANGE: THE INTERACTION OF POLICY, PERCEPTIONS, AND ECOLOGICAL KNOWLEDGE

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Abstract

The National Wildlife Refuge System (NWRS) is committed to conserving fish, wildlife, and plants for current and future generations of Americans. Given a rapidly changing climate, managers may employ various adaptation strategies to meet legislated mandates. I explore how ecological context, policy, perceptions and available ecological knowledge inform adaptation strategies. In Chapter 2, I develop an ecosystem vulnerability framework to better understand how climate change risk and ecosystem resilience interact to impact the NWRS. With GIS, I rank refuges based on historic temperature change, historic precipitation change, and sea-level rise risk. To index resilience, I rank refuges based on refuge size, landscape road density, and elevation range. Using this GIS analysis and the ecosystem vulnerability framework, I categorize the 527 refuges into four groups (refugia, ecosystem maintenance, facilitate transitions, and experiments in natural adaptation) that provide a necessary context for national, strategic adaptation planning. In Chapter 3, I survey 32% of NWRS biologists and managers to understand how policy and their perceptions of climate change influence adaptation choice. Currently, managers and biologists independently decide if climate change is natural or anthropogenic for wildlife management, and this conceptualization becomes important for deciding whether reactionary or anticipatory adaptation approaches are more appropriate. Although respondents considered practicability, they prefer historic condition. Respondents also prefer ecosystems and species adapt naturally. In a rapidly changing climate, natural adaptation may not be feasible without large-scale extinction. Nonetheless, many biologists and managers are uncomfortable with the alternative of manipulating ecosystems and species assemblages toward future conditions. Finally, understanding climate change impacts requires the analysis of complex ecological relationships over time and this complexity creates another barrier for implementing a national adaptation strategy. In Chapter 4, using a data-mining

approach on data from scaled-down GCMs and an atypical monitoring approach, I build bioclimatic envelope models to show how the distributions of two passerines will potentially shift in response to climate change over the next 100 years on Kenai National Wildlife Refuge. In order to effectively manage species within the context of strategic adaptation planning, the NWRS must design future biological monitoring approaches with spatial modeling in mind.

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Chapter 1 Introduction

The National Wildlife Refuge System (NWRS) is managed by the U.S. Fish & Wildlife Service with the legislated mission to "*administer a national network of lands and waters for the conservation, management, and where appropriate, restoration of the fish, wildlife, and plant resources and their habitats within the United States for the benefit of present and future generations of Americans*" (Public Law 105-57). The NWRS grew with early conservation movements in the United States, and it has continued to be the leading federal organization concerned with environmental issues affecting wildlife. Since the NWRS's inception in 1903, refuge policies have changed in response to new conservation problems. Within the past 20 years, climate change has emerged as a conservation problem that challenges many assumptions in wildlife management.

Climate change has been defined as a wicked problem: complex at all levels, riddled with uncertainty, and influenced by multiple, plausible perspectives (Ludwig 2001). For wildlife managers, climate change impacts involve complex ecological interactions that are difficult to understand and predict. Furthermore, climate change challenges the logic behind many current management practices like the use of ecological baselines to measure management success. In general, management decisions depend on both social factors and ecological realities (Figure 1.1). Social factors include NWRS policy and the individual beliefs managers hold about conservation. In other words, managers will have multiple, plausible ideas about how best to manage changing ecosystems. Ecological realties are filtered by the information available to detect and understand ecosystem change, and this information mediates management response.

For my dissertation, I address the over-arching question: How can climate change be incorporated into NWRS planning, given the uncertainty associated with future conditions and the multiple perspectives about which changes are acceptable? Providing strategies to address climate change within a planning process is critical because wildlife biologists have traditionally managed lands under the assumption of a stable climate. Managers will need to address uncertain future conditions to plan for climatic changes. In addition, with no baseline management condition, managers will need to decide what future conditions are acceptable. Specifically, I ask:

- How is climate change currently affecting the NWRS given the spatial distribution of lands (Chapter 2)?
- How can individual refuges within the NWRS be strategically organized to define the suites of adaptation options that will be beneficial to the NWRS as a whole (Chapter 2)?
- To date, how has climate change been included in NWRS planning (Chapter 3)?
- Which factors influence preference for reactive adaptation toward historic conditions and anticipatory adaptation toward future conditions (Chapter 3)? Specifically, I test the following hypotheses:
    - *Landscape Context*: H1 Managers and biologists in areas with low ecosystem resilience will prefer reactionary strategies because other anthropogenic stressors will mask climate change impacts;
    - *Climate Change Rate*: H2 Managers and biologists in geographic areas currently experiencing climate change impacts will be more likely to prefer anticipatory strategies;
    - *Establishment Purpose*: H3 Managers and biologists with refuge purposes that are focused on endangered species or natural systems will prefer reactionary strategies;
    - *Conceptualization of Problem:* H4 Managers and biologists that believe climate change is an anthropogenic process will prefer reactionary strategies;

    - *Planning Process*: H5 Refuges with management documents addressing climate change will be more likely to prefer anticipatory strategies;
- Which management approach, with associated technical tools, could help managers address climate change (Chapter 4)?

In Chapter 2, I use the concept of ecosystem vulnerability to develop a framework that is useful for understanding how climate change affects NWRS lands. Ecosystem vulnerability considers the interaction of climate change impacts with ecosystem resilience. The ecosystem vulnerability framework also provides a strategic rationale for organizing adaptation options.

In Chapter 3, I investigate whether climate change has been addressed to date in NWRS planning processes. In addition, I explore how NWRS managers and biologists conceptualize viable adaptation approaches. Climate change challenges the validity of a historical baseline, which is a fundamental assumption in wildlife management and conservation (Arcese and Sinclair 1997, Davis 2000). Some adaptation options, like assisted migration, are incongruent with historic ecological conditions that provide a management baseline. Adaptation options that focus management toward future conditions may conflict with policies and managers' beliefs about conservation. Managers will ultimately implement any strategically planned adaptation strategy. An understanding of managers' beliefs may help to define values inherent in adaptation goals for the NWRS. In addition, these beliefs will need to be addressed in order to effectively communicate the rationale behind a national adaptation strategy.

Finally, understanding climate change impacts requires the analysis of complex ecological relationships over time, and this complexity creates another barrier for implementing a national adaptation strategy. Managers must first use available information to detect ecological changes. Once detected, they must decide whether to restore past ecological conditions or encourage new conditions. Managers have indicated that understanding when to restore past conditions is problematic (GAO 2007). In Chapter 4, I use breeding passerines on the Kenai National Wildlife Refuge as a case study to provide an example of how to leverage monitoring data to detect and understand climate change impacts. The management approach of linking species distribution modeling with monitoring programs could be widely implemented throughout the NWRS.

1.1 BACKGROUND

In my dissertation, I investigate how NWRS managers conceptualize climate change as a conservation problem and provide an approach to detect and respond to ecological changes. In order to understand climate change in the context of policy, I provide a background history of the NWRS. In this background section, I also review recent climatic changes and their effects on wildlife. Next, I introduce the concept of resilience. Climate change has challenged key assumptions in ecology and management. Resilience provides a framework that incorporates ecological change. I approach the problem of climate change as a social-ecological system in which humans are integrated into ecology. Therefore, the decision-making processes of managers, including their belief systems regarding climate change, are an integral component of ecosystems. I provide an overview of the importance of belief systems. Finally, I outline the components of a management approach for climate change.

1.1.1 National Wildlife Refuge System

The NWRS includes 527 refuges and wetland management districts in the United States (Figure 1.2). Besides refuge lands, the NWRS also includes coordination areas that are federally owned lands managed by states under cooperative agreements or long-term leases (Fischman 2003). In this work, I focus on refuge lands within the United States.

1.1.1.1 *History and Policy Change*

The NWRS includes lands of difference sizes, ecosystems, climates, ownership regimes and development (Fischman 2003). Each refuge within the NWRS has specific purposes outlined at the time of establishment. Beginning in the early 1900s, emerging conservation movements in the United States have greatly influenced NWRS growth. Punctuated equilibrium is a political framework that seeks to explain why, over long timescales, policy will undergo long periods of incremental change and then bursts of rapid restructuring (True et al. 1999). Factors such as institutionalism and professionalism provide negative feedbacks that stabilize the policy subsystem and result in only incremental change to current policy (Figure 1.3). Occasionally, a change in the policy venue or policy image will result in a rapid restricting of the policy subsystem. Changes to the policy venue occur when new actors enter the debate or the jurisdiction changes. The policy image usually changes when the policy problem becomes redefined. Punctuated equilibrium had been applied to explain changes in U.S. environmental policy (Repetto 2006). In this section, I argue that change in the policy image for wildlife and the redefinition of wildlife needs by key actors has been integral to major changes in NWRS policy.

In the early 1900s the policy image for wildlife species was one of an unending resource that did not need protection. The first European settlers harvested unlimited supplies of game for personal use and market sales with few restrictions beyond private property rights (of hunting lands, not game species). Focusing events, like the extinction of the passenger pigeon (*Ectopistes migratorius*) and the rapid decline of marine mammals, brought public attention to wildlife issues and shifted this policy image to one of conservation. During this time, the policy venue also expanded from only hunters and business profiting from wildlife sales to bird watchers and others interested in the non-game values of wildlife. Rapid policy change restructured government agencies to handle wildlife issues, gave government the authority to regulate wildlife, and allowed the establishment of the first wildlife refuges. Major changes in government authority include the Lacey Act in 1900 that empowered law enforcement to regulate wildlife trade across state boundaries and gave this responsibility to the newly established Division of Biological Survey. Changes to government authority of bird species include the Weeks-McLean Migratory Bird Act of 1913 which gave government the authority to manage hunting for migratory birds and the Migratory Bird treaty Act of 1918 which was a treaty between the U.S. and Canada (via Great Britain) to protect migratory birds. Changes to land acquisition and federal control of lands for wildlife protection began with President Theodore Roosevelt establishing the first national wildlife refuge at Pelican Island in 1903 with an executive order that set aside the land as a "*preserve and breeding ground for native birds*". Pelican Island set a precedent that allowed the President and Congress to reserve lands for wildlife conservation purposes outlined in the establishment orders or legislation (Fischman 2003). Between 1903 and 1909, Roosevelt decreed an additional 51 bird and 4 big game reserves.

After this initial period of change, wildlife policies remained stable around the concept of wildlife conservation with lands set aside to provide sanctuary. However, the environmental devastation surrounding poor management of agricultural lands that culminated in the Dust Bowl shifted the broad environmental policy image from conservation to management. This image spilled over to wildlife. Aldo Leopold packaged this new information into his 1933 classic work *Game Management* (Leopold 1933). President Franklin Roosevelt expanded the policy venue to include actors with this view by appointing Aldo Leopold, Thomas Beck, and Ding Darling to a Presidential Committee on Wildlife Restoration to make recommendations for the improvement of wildlife resources. This committee helped to increase funding for management with the establishment of the 1934 Duck Stamp Act. In 1937 more money was provided for management when the Federal Aid in Wildlife Restoration Act (Pittman-

Robertson Act) enacted a tax on hunting equipment. During this time, government agencies also restructured when the Bureau of Fisheries and the Bureau of Biological Survey combined to form the Fish and Wildlife Service. After these major structural changes, a period of relative stability ensued with only small increases in funding for wildlife management on refuges.

The 1960s began another shift in policy image from management to environmentalism when Rachael Carson packaged information about pesticides and other large-scale problems affecting wildlife in her book *Silent Spring* (Carson 1962). This policy image shift led to a suite of environmental legislation in the 1960s and 1970s including the Endangered Species Act and the Wilderness Act. Managers on isolated refuges were facing habitat degradation as recreation and development pressures increased due largely to post World War II economic growth (Curtin 1993). The 1962 Refuge Recreation Act coordinated all refuges with systemic management guidelines aimed at protecting wildlife from these pressures: specifically that recreation would only be allowed if compatible with wildlife. The 1966 Refuge Administration Act achieved further coordination and reinforced a commitment to protect wildlife. The 1966 Refuge Administration Act also created an official System of lands, named the NWRS, with a consistent mandate to conserve fish and wildlife above all other uses.

The most recent shift in wildlife policy images began in the 1990s with the listing of the Northern Spotted Owl (*Strix occidentalis caurina*) as an endangered species and the recognition that management must occur at landscape scales. During this time, the policy venue also expanded to include environmental groups who entered via litigation pathways. This shift brought the current notion of ecosystem management. Slightly ahead of its time, the Alaska National Interest Lands Act of 1980 (ANILCA) added vast tracks of lands to the NWRS with refuge purposes that are based on ecosystem properties. In addition, ANILCA provided tools for management that Congress would later apply to all refuges like comprehensive planning and a hierarchy of purposes to help in decision making.

The National Wildlife Refuge System Improvement Act of 1997 (Refuge Improvement Act) reinforced the organization of all refuges into a system and broadly reformed refuge administration. The Refuge Improvement Act provides the NWRS with a legislated commitment to ecosystem protection and embraces concepts of ecological integrity and ecosystem management.

The Refuge Improvement Act is the most influential legislation currently affecting the NWRS, so I have provided a detailed description. The Refuge Improvement Act outlined the unifying conservation mission of species and habitat protection for the NWRS. Specific management guidance is also given through a hierarchy of designated uses for refuge lands, substantive management criteria, and a strategic planning process. The hierarchy of designated uses elevates wildlife first, wildlife-dependent recreation second, and then all other uses. The Refuge Improvement Act acknowledges the history of establishment purposes. When refuge establishment purposes conflict with the hierarchy of uses, establishment purposes provide the primary guidance for refuge management. Substantive management criteria are used to evaluate the success of Refuge System administration. Substantive management criteria include the compatibility of all refuge activities with conservation; the maintenance of biological integrity, diversity, and environmental health; water right acquisition; ecological monitoring; and conservation stewardship. The Refuge Improvement Act also provides guidelines for a strategic planning process: the Comprehensive Conservation Plan (CCP). Refuge staff must develop a CCP every 15 years. Within the CCP, each refuge is required to identify and describe (1) *"the purposes of each refuge comprising the planning unit"*; (2) *"the distribution, migration patterns, and abundance of fish, wildlife, and plant populations and related habitats within the planning unit"*; and (3) *"significant problems that may adversely affect the populations and habitats of fish, wildlife, and plants within the planning unit and the actions necessary to correct or mitigate such problems"* (Public Law 105-57). CCPs must include a vision statement, management goals, and management alternatives. An open process, which includes both agency personnel and the public, is used to develop the CCP.

Climate change challenges some assumptions in policies related to the Refuge Improvement Act. The 2001 Policy on Maintaining the Biological Integrity, Diversity, and Environmental Health of the National Wildlife Refuge System (BIDEH; RIN 1018-AG47) invokes naturalness and historical conditions, two concepts that are problematic in the context of climate change. The objective of the BIDEH policy is to provide managers with guidelines for meeting the substantive management criteria of "*maintaining, and restoring where appropriate, the biological integrity, diversity, and environmental health of the National Wildlife Refuge System".* Biological integrity is defined in terms of natural biological processes, and environmental health is related to natural abiotic processes. In both cases, naturalness implies that humans have not altered these processes. Anthropogenic climate change is a global phenomenon; therefore, no refuge has escaped human influence. BIDEH policy would have managers use historic conditions as a baseline to measure and manage biological integrity, diversity, and environmental health. BIDEH policy defines historic conditions as present prior to substantial human development of the landscape. With climate change, historic conditions may be impossible to restore and maintain.

1.1.1.2 *Case Study: Kenai National Wildlife Refuge*

I use the Kenai National Wildlife Refuge (Kenai NWR) as a case study for detecting and monitoring climate change impacts. The Kenai refuge is an excellent case study because there is a well-designed monitoring grid established (Morton et al. 2009).

The Kenai NWR encompasses 7722 km^2 on the Kenai Peninsula in South-central Alaska (Figure 1.4). The large size provides a significant challenge for both monitoring and mapping ecological conditions. In addition, Alaska is experiencing faster rates of climatic change than other regions in the United States (ACIA 2005). The Kenai NWR also includes the interface between the boreal and coastal rainforest ecoregions. Ecoregion boundaries will likely be hotspots for range expansion and contraction (Hampe and Petit 2005). Elevation ranges from sea level to 2000 m in the Kenai Mountains on the eastern refuge boundary. The ecoregion interface and elevation gradient provide a diverse range of habitats that increase biodiversity on the Kenai NWR. Boreal lowlands occur west of the Kenai Mountains and include pothole lakes, peatlands, and forest mosaic consisting of black spruce (*Picea mariana*), white spruce (*P. glauca*), Lutz spruce (*P.* Lutzii) aspen (*Populus tremuloides*) and birch (*Betula neoalaskana*) stands. Sitka spruce-dominated (*P. sitchensis*) stands occur in the coastal southern portions of the refuge. Mountain hemlock (*Tsuga mertensiana*) and sub-alpine shrub habitats turn to lichen-dominated tundra along the elevation gradient, and glaciers and ice occur along on the eastern refuge edge (Hulten 1968).

1.1.2 Climate Change

The Intergovernmental Panel on Climate Change (IPCC), an international group of scientists and other experts, conclude the global climate system is changing due to radiative forcing from human activities (Solomon et al. 2007). The net effect of radiative forcing is a warming trend; the global average surface temperature has increased 0.74 °C ± 0.18 °C since the early 1900s with the rate of increase doubling since the 1950s (Trenberth et al. 2007). Precipitation patterns have also been affected; droughts are more common in some regions while the number of heavy precipitation events has also increased (Trenberth et al. 2007). Climate change impacts to the earth's physical and biological systems have been documented on every continent (Rosenzweig et al. 2007). Even if greenhouse gasses and other radiative forcing agents were stabilized through mitigation efforts, climate change would be expected to continue due to time lags in climate systems (Meehl et al. 2007). Therefore, some impacts will be unavoidable and adaptation strategies will be necessary. Adaptation is defined by the IPCC as "*the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects which moderates harm or exploits beneficial opportunities*" (Parry et al. 2007: 6). I use this definition of adaptation because it is explicitly relevant to climate impacts.

Documented impacts to physical systems include changes in oceans, the cryosphere, and terrestrial hydrology. Global ocean temperatures have increased and sea levels have risen due to thermal expansion and land-ice melt (Bindoff et al. 2007). Ocean salinity has changed regionally and surface acidity has increased (Bindoff et al. 2007). Ice is decreasing on Earth with glacial retreat, the loss of arctic sea ice, shortened durations of seasonal lake and river ice, and ice thinning in the Antarctic Peninsula and Amundsen shelf (Lemker et al. 2007). Lakes and rivers are generally warming causing changes in thermal structure and water quality (Rosenzweig et al. 2007). Temporal river dynamics are also changing with earlier spring discharge in rivers fed by snow melt (Rosenzweig et al. 2007). On the Kenai NWR, lowland wetlands are drying (Klein et al. 2005). Harding Icefield melt charges major rivers, like the Kenai River, that flow through the Kenai NWR. Changes in ice pack and melt rates would dramatically alter hydrology. From 1950 - 1990, the Harding Icefield has lost 21 m in elevation (Adalgeirsdottir et al. 1998).

Biological systems have already and will continue to be affected by climate change. Across taxa, species are shifting distributions northward and phenological events earlier, producing a globally coherent fingerprint of climate change impacts to biological systems (Parmesan and Yohe 2003). Changes in the abundance of some species have also been attributed to climate change (Rosenzweig et al. 2007). Shifts in the distribution of entire biomes have been projected (Joyce and Birdsey 2000), but historical evidence of past climatic transitions indicate that species move at different rates and not as an ecosystem unit (Root and Schneider 2001). Individual species respond independently due to differences in physiology, life-history, and dispersal ability (Parmesan 2006). The independent nature of distributional and phenological shifts may lead to asynchrony with food or habitat resources (Parmesan 2006). In the future, novel assemblages may overlap with the potential for community restructuring. New species can alter predation and competitive interactions in current ecosystems. Rapid, non-linear changes to ecosystems have occurred when communities change (Scheffer et al. 2001, Folke et al. 2004). The Kenai NWR lies at the interface of the boreal and coastal rainforest ecoregions. Coastal species are expected to expand northward. For example, Sitka Blacktail Deer (*Odecoileus hemionus sitkensis*) may compete with moose (*Alces alces*) in the future. Moose were, and continue to be, highly valued by residents on the Kenai Peninsula, so lowered moose populations would be a contentious management issue. Elevation also delineates many habitat types on the Kenai NWR. Treeline has risen 1 meter per year within the past 50 years (Dial et al. 2007). Alpine habitats, considered sky islands, will likely be lost with continued warming. Spruce bark beetle outbreak, linked to warm summer temperatures, has caused high white, Lutz, and Sitka spruce mortality; and beetle kill may now influence the fire regime (Berg et al. 2006).

Climate change impacts on wildlife are expected to be exacerbated by synergistic interactions with other human drivers (i.e., land-use change, over-exploitation, and conflict or wars). Climate change may have more profound effects in landscapes with fragmented habitat because barriers to dispersal may cause species to become locally extinct (Root and Schneider 2001). Higher densities of human footprint on the landscape and increased agricultural land-use could increase the potential for invasive species to be transported into the region. Invasive species may cause an initial increase in species diversity locally, but over time decrease functional diversity and change species composition. The synergistic effects of climate change will be difficult to predict and manage because they are cumulative in nature (Koteen 2002). Development pressure and fragmentation occur along the Kenai NWR boundaries. Four exotic plant species have been documented in the Kenai NWR (Morton et al. 2009). Consequently, the Kenai NWR provides an excellent case study area due to both latitude amplification of climate effects and development pressure.

1.1.3 Conceptualizing Environmental Change in Ecology and Management

1.1.3.1 *Resilience Theory*

In the past, ecologists and managers viewed ecosystems based on a concept of equilibrium where changes in the environment would be compensated by negative feedback mechanisms (Chapin et al. 1996). More recently, ecologists and managers have recognized that ecosystems have the potential to be organized into multiple stable states (Gunderson and Holling 2002). Transitions between ecosystem states are un-predictable and non-linear. Variables operating on slower time scales were usually considered stable in equilibrium models (i.e., climate, soil structure and species composition). However, these slow variables can exceed a threshold that can cause the system to restructure. Restructuring often occurs after a disturbance. In these cases, ecosystems exhibit rapid, non-linear shifts to alternative states that are difficult to reverse when complex interactions and feedbacks between system components reorganize (Scheffer et al. 2001). For example, freshwater-lake ecosystems can shift from a clear water state to a turbid state when changes in predator assemblages cause trophic cascades resulting in changes to species dominance (Carpenter 2003). On the Kenai NWR, climate change may increase fire frequency and shift mixed conifer-deciduous forests to primarily deciduous forests (Paine et al. 1998). Environmental change, both natural and anthropogenic, and other surprises should be expected in these complex, adaptive systems. However, scientists may gauge the resilience of the system. Resilience can be defined as "*the capacity of a system to absorb disturbance and reorganize while undergoing* *change so as to still retain essentially the same function, structure, identity, and feedbacks*" (Walker et al. 2004: 2).

1.1.3.2 *Resilience Management*

Resilience-based management is a new approach that challenges many of the paradigms of conventional resource management (Chapin et al. 2009). Both conventional and resilience-based resource management strive to achieve sustainable resource utilization for human benefit. However, these management paradigms differ in approach and in their underlying assumptions about ecosystems. Conventional management has utilized a command-and-control approach that seeks to minimize variability in the system in order to maintain stable outputs (Holling and Meffe 1996). Conventional management also largely operates under equilibrium assumptions where negative feedbacks work to restore the ecosystem to a stable equilibrium (i.e., carrying capacity population size). This understanding of the system is used to optimize ecosystem outputs using models like maximum sustainable yield (Gunderson and Holling 2002). Generally, past conditions are thought to be useful for understanding and anticipating future conditions. Conventional management approaches also tend to focus on a single species and expect that most species will respond in a predictable, continuous manner as the variables that limit their population change.

In contrast, resilience-based resource management views the ecosystem as a complex, adaptive system where a number of stable equilibrium states are possible. In addition, ecosystems are known to be subject to rapid, non-linear changes in structure as environmental variables change, and these changes are often triggered by disturbance (Scheffer et al. 2001). Therefore, resilience-based managers work to accept change and uncertainty, maintain system diversity in order to maintain the capacity for reorganization, and constantly learn from, respond to, and shape changes (Folke et al. 1993). In addition, resilience-based managers are cognitive of controls like climate, soil resource supply, the major functional groups of organisms, and disturbances regimes (Chapin et al. 1996) and work to monitor and understand how these controls factor into ecosystem stability. Resilience-based managers may also look for opportunities to actively transform the system to a fundamentally new system (Walker et al. 2004). Active transformation would require that research and learning be interdisciplinary and speculative in order to evaluate options that may not occur to disciplinary researchers acting in isolation (Chapin et al. 2004).

I use the example of a changing fire regime that is increasing in frequency and duration due to a warming climate to compare and contrast how conventional and resilience-based managers would apply different strategies. Conventional managers would use historical variability as a benchmark to define a natural fire regime. If fire frequency was outside this benchmark and shifting mixed forests to deciduous forests, conventional managers would use fire suppression techniques to maintain mature conifer forest stands. Resilience-based managers would be hesitant to suppress fires across the landscape because the warmer climatic conditions would limit the likelihood of controlling fire frequency in the future. Although fire suppression may be possible over short time scales, fire suppression in warm conditions would prime the landscape for an uncontrollable, large fire. Instead, resilience-based managers would allow the fire frequency to increase and the forest to shift to deciduous stands. Prescribed burns could be used to reduce the likelihood of large fires that would damage human infrastructure. Resilience-based managers would also ensure that species associated with mature conifer forest would be viable in the future. Resilience-based managers may also use intensive management in the short term to help any sensitive species adapt, via migration, to the emerging ecosystem conditions. In this case, adaptation refers to reducing harm or exploiting beneficial opportunities for the species.

1.1.4 Social-ecological Systems: Ecosystems Interact with Policy and Belief Systems

Resilience management requires analysis of ecological and social systems in an integrated framework (Berkes and Folke 2000). In a social-ecological systems framework, humans and ecosystems are both part of a complex, adaptive system. Humans and their social systems can be agents of change to ecosystems and are also affected by ecosystem change. Adaptability has been related to resilience as the capacity of actors in the system to influence resilience (Walker et al. 2004).

Humans interact collectively with ecosystems, affecting resilience, under the constraints of environmental policies. However, understanding how ecosystems will be affected is difficult even when policy goals are clear. Indeed, policy intent and policy implementation can be disconnected (Howlett and Ramesh 2003). In the United States, the laws created by government are generally passed to administrative agencies for a process of elucidation whereby detailed regulations are formed in order to implement policies. Principle-agent theory suggests that this relationship between politicians and administrators can cause an inherent compliance problem because administrators have their own perceptions and beliefs (Howlett and Ramesh 2003). Understanding policy implementation can be more difficult when policy goals are explicitly open for interpretation.

The substantive management criteria in the Refuge Improvement Act to maintain ecosystem integrity, diversity, and environmental health are examples of this tension because the language is vague and generally used heuristically (Gergely 2003). Furthermore, the concepts of biological integrity, diversity and environmental health have been identified by some as normative concepts that fall under different schools of conservation philosophy, which calls into question whether people will interpret the language in the Refuge Improvement Act consistently (Callicott et al. 1999). Indeed, managers in the NWRS were found to make management decisions based on personal preferences and only justify these preferences with scientific evidence when challenged by the public (Gergely 2003).

Therefore, managers' beliefs influence management preferences. Although often described as objective, the very process of generating scientific knowledge is subjective and influenced by cultural assumptions (Haraway 1991, Harding 1998). Scientific statements usually include these unstated, normative values of the scientist (Rykiel 2001). For example, conservation scientists often confuse the practice of the scientific method with conservation values like risk-aversion which can lead to distortions of evidence, failures to consider alternative hypotheses or evidence, and avoidance of discussing alternatives that are unappealing (Walters 1998). Adding complexity, scientific terms and facts take on other meanings when they are employed in alternative social contexts. The meaning of a scientific fact can only be understood from the perspective of the belief system or personal narrative in which the fact becomes embedded (Weber and Word 2001). Individuals tend to incorporate scientific facts that support their belief system and resist or dismiss facts that are contradictory. Therefore, belief systems are relatively stable over time because individuals filter information based on these systems (Sabatier and Jenkins-Smith 1999).

Sabatier and Jenkins-Smith (1999) explicitly include belief systems in a model of the policy process, the advocacy coalition framework. The policy process includes all stages of a policy cycle from the initial problem definition to policy implementation and evaluation (Howlett and Ramesh 2003). The advocacy coalition framework studies the policy process as a policy subsystem, organized around a policy problem or issue, where actors in different coalitions compete to realize their policy objectives. The core beliefs of actors form a lens through which they perceive the world and evaluate information. Actors with similar belief systems form policy coalitions that are not necessarily congruent with institutional affiliations. Scientists and agency personnel are also coalition members and not objective observers. Within this framework, the core values of belief systems are a causal driver of actor behavior. Therefore, policy implementation cannot be fully understood without understanding both the belief systems of the actors charged with implementation and the legislative intent of policies.

1.1.5 A Management Approach for Climate Change

Climate change is a difficult management problem because the ecological impacts are complex. In order to understand climate change impacts, managers must be able to detect ecological changes. Future ecological conditions are uncertain and difficult to predict because climate change shifts key variables outside of their known ecological limits. In addition, ecosystems are complex systems with multiple interactions that are difficult to understand mechanistically. In my dissertation, I present an approach to synthesize existing knowledge for climate change management on the Kenai National Wildlife Refuge. The management approach requires multiple methodologies, outlined in the following section, to document current conditions and understand future conditions.

1.1.5.1 *Understanding Current Ecological Conditions and Detecting Change*

Environmental management policies often include instructions to collect information about ecological conditions in order to understand the impacts of management practices (Walters 1986). The Refuge Improvement Act requires managers to document and review ecological conditions in Comprehensive Conservation Plans. However, most refuges do not have complete species inventories (Meretsky et al. 2006, Scott et al. 2008). Most monitoring programs have been associated with narrow refuge purposes and focus on a single species or taxonomic group. Climate change requires more comprehensive monitoring of current ecological conditions in order to understand climate change impacts.

1.1.5.1.1 *Inventory & Monitoring Programs*

Inventory and monitoring programs provide a quantitative, information feedback from the ecological to the social subsystem. Inventory programs provide a systematic determination of ecosystem status for a single point in time while monitoring programs collect information across time to determine trends in ecosystem status (Busch and Trexler 2003). Inventory and monitoring programs are designed based on informational needs. Three basic categories of monitoring needs are targeted, cause-and-effect, and context (Holthausen et al. 2005). Targeted monitoring is focused on a specific species or habitat in order to measure initial condition and response to management actions. Cause-and-effect monitoring actively manipulates a system in order to test the current, causal understanding of the mechanisms controlling a given system. Cause-and-effect monitoring requires a scientific design with alternative treatments and controls (Walters 1986). Context monitoring tracks a suite of ecosystem variables without specific reference to current management actions. Monitoring programs without specific questions about management or causal mechanisms, like context monitoring, have been critiqued for being inefficient (Nichols and Williams 2006). However, unanticipated ecosystem changes that are likely to occur with climate change may not be captured by targeted or cause-and-effect monitoring (Bella et al. 1992). Climate change requires a new vision and approach to monitoring because conceptually narrow monitoring provides inadequate information for understanding overall ecological conditions (Karr 2004). The NWRS is in dire need of effective monitoring and inventory strategies; many refuges currently lack species inventories (Meretsky et al. 2006, Scott et al. 2008).

In order to limit the programmatic scope, monitoring programs must be designed around a selected element like a species, population, community, or habitat and a selected scale (Holthausen et al. 2005). Population monitoring metrics include occurrence (MacKenzie et al. 2006), density (Buckland et al. 2001), and demographic rates (Beissinger and McCullough 2002). Community metrics include diversity measures like species richness and ecological integrity measures that compare conditions to a natural baseline. Habitat metrics address the composition and structure of vegetation. Predictive, spatial models, like species distribution models, can provide a link between population metrics and habitat metrics (Scott et al. 2002). When distribution models are used for monitoring, the spatial prediction from the model becomes a metric that can be employed as an indicator of environmental change (Bella et al. 1992, Magness et al. 2008).

1.1.5.1.2 *Predictive Modeling of Species Distributions*

Species distribution models provide a powerful monitoring metric because they link processes affecting species, populations, and habitats (Scott et al. 2002). Species distribution models usually describe the relationship between the occurrence of a wildlife species and a set of predictor variables describing the environment (Figure 1.5). Generally, modern distribution models build on the niche concept with the assumption that predictable relationships can describe the range of environmental conditions where an animal occurs (Heglund 2002). The ecological niche can be defined as either the fundamental niche (includes all suitable environmental conditions) or the realized niche (area where the species actually occurs). For accurate predictions over limited spatial and temporal scales, modeling efforts would likely capture the realized niche, a narrower range of conditions than the fundamental niche (Guisan and Zimmermann 2000).

The choice of predictor variables used to describe the niche affects the modeling process. Predictor variables can represent a wide variety of ecological processes and conditions. Based on the niche concept, predictor variables have been conceptually separated into usable resources (food, habitat) and constraints on those resources (predation, competitive exclusion) (Morrison 2002). A more detailed conceptualization breaks predictor variables into (i) limiting factors that describe the physiological limits of a species, (ii) dispersal factors including barriers and historical features that limit current distributions, (iii) disturbance factors that represent past extreme events or cyclic variables, and (iv) resource factors that affect the patchy distribution of energy sources and shelter (Guisan and Thuiller 2005). Physiological limiting factors may be more influential over broad, geographic scales. Dispersal, disturbance, and resource factors are likely to influence distributions among patches over smaller spatial scales.

Both parametric statistics and data-mining approaches can be used to build species distribution models describing the relationship between species occurrence and the predictor variables (for example Elith et al. 2006). Although both approaches are useful, parametric statistics and data-mining have been described as two statistical cultures with different philosophies and goals (Breiman 2001, Hochachka et al. 2007). Parametric statistics, like general linear models (GLMs), require *a priori* knowledge of the ecological system in order for the researcher to define a data model; parameters are then estimated for this data model. Model evaluation in parametric statistics focuses on how well the data fit the researcher-defined data model. Parametric statistics are useful for hypothesis testing and therefore provide a framework for confirmatory analysis of the mechanisms driving a species distribution. Therefore, parametric statistics are more useful for targeted and cause-and-effect monitoring programs.

In contrast, data-mining approaches require no *a priori* assumptions about the relationship between species occurrence and predictor variables (Breiman 2001, Hochachka et al. 2007). Data-mining approaches use algorithms to filter many predictor variables and find patterns in large, complex datasets. Therefore, data-mining is a powerful tool for context monitoring. Data-mining approaches use predictive accuracy for model evaluation. In order to increase predictive power, data-mining approaches embrace the assumption that multiple models can describe a process, aggregate many models to leverage information, and allow complex models (non-linear, with interactions, not parsimonious). However, the multiplicity of models and complexity make interpreting the importance and meaning of the predictor variables difficult. Therefore, data-mining approaches are useful for producing accurate predictions (map output of species distribution) quickly when there is little understanding of the ecological processes driving a species distribution. The information gained through pattern recognition in data-mining can also be used to formulate hypotheses to be tested by future, confirmatory research.

An inherent tradeoff exists between describing ecological mechanisms that are universal and high predictive accuracy within a study area (Guisan and Zimmermann 2000). Mechanistic models produced with parametric statistical approaches generally have lower predictive power within the study area, but should be transferrable to other geographic areas. Models that maximize predictive accuracy using data-mining can be highly accurate within the response space, as evaluated by the predictive accuracy when applied to a validation dataset, but may not be as useful outside the landscape where they were developed.

1.1.5.2 *Understanding Future Ecological Change*

Wildlife managers need to include climate change in conservation planning efforts, but this is a challenging endeavor because current conditions need to be accurately documented and future conditions are uncertain. Baseline inventories of biodiversity and fine-scale information about current species distributions are lacking and this provides a significant data-gap for management (Usher et al. 2005, Meretsky et al. 2006, Scott et al. 2008). Forecasting future ecological conditions is also needed for planning, but is difficult because the rates of current global change exceed historic rates by an order of magnitude, the processes operate at multiple scales, multiple disciplines must be integrated, and uncertainty is propagated (Root and Schneider 1995).

Species distribution models provide a method for both accurately documenting current species distributions and forecasting future conditions. However, the goals of accurately predicting current conditions and forecasting future conditions fit into separate, but complementary frameworks of scientific inquiry (Bella et al. 1992). When working to accurately predict current conditions in unsampled areas, the species distribution model provides a metric (i.e., map) that can be used as an indicator of future ecological change (Magness et al. 2008). Metrics of current conditions are useful for understanding future environmental change because they can alert managers to surprises and unforeseen management issues that arise as ecological systems adapt. In contrast, to forecast future conditions, the species distribution becomes a conceptual model that is used to describe our current understanding of the mechanisms driving the distribution and to predict expected outcomes as conditions change. New information must be gathered to test and refine the conceptual model.

In this investigation, I use species distribution models to generate accurate predictions of current conditions within the sampled study area. In addition, I forecast future change given changes to climatic variables. However, I argue that species distribution models are only the first step toward understanding climate change impacts. Root and Schneider (1995) advocate using both the information and ideas generated from large-scale patterns, like distribution models aimed with the goal of predicting current conditions, and small-scale studies designed to test conceptual models of mechanisms. Cycling continuously between strategically designed small-scale studies and large-scale monitoring will deliver credible information to managers more quickly and efficiently. Agencies will be best served by a long-term commitment to management planning in which monitoring programs and scientific studies work together. For example, current predictions of species distributions can be compared with predictions generated with repeat monitoring information in order to detect areas of range expansion and contraction (Magness et al. 2008). These areas of range expansion and contraction can then be studied in order to understand the mechanisms driving change.

1.2 SUMMARY

Climate change will provide new management challenges for maintaining the biological integrity, diversity, and environmental health of lands within the NWRS. Managers may employ various adaptation strategies to meet legislated mandates when faced with climate change impacts. However, management decisions about when to act and which adaptation strategies are acceptable will be based on the climate impacts occurring on NWRS lands and the ability of managers to detect and understand ecological change. NWRS policies in conjunction with the belief systems of managers, will also affect management response. In this work, I explore the interplay between current climate change impacts, policy, belief systems, and information.

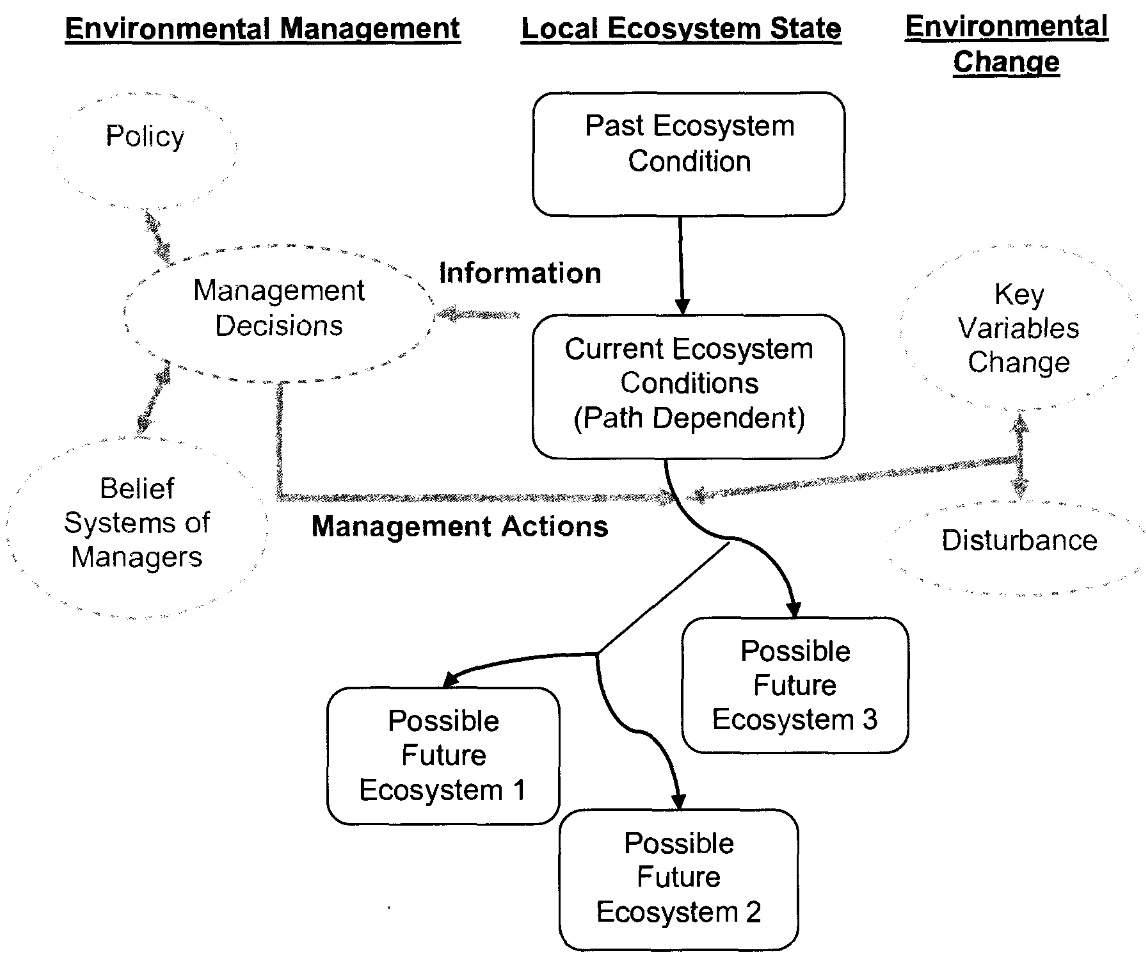

Figure 1. 1. Conceptual Model of Ecosystem Change. Ecosystems (represented in black) are path dependent and multiple states, called resilience basins, are possible in the future. Factors that influence future ecological conditions (represented in blue) include both management and ecological conditions. Management actions are affected by the information available about current ecosystem conditions, policies, and the belief system of the managers that provides a lens through which they interpret information. Environmental change, interacting with disturbance and management actions can affect ecosystem resilience and future ecological conditions.

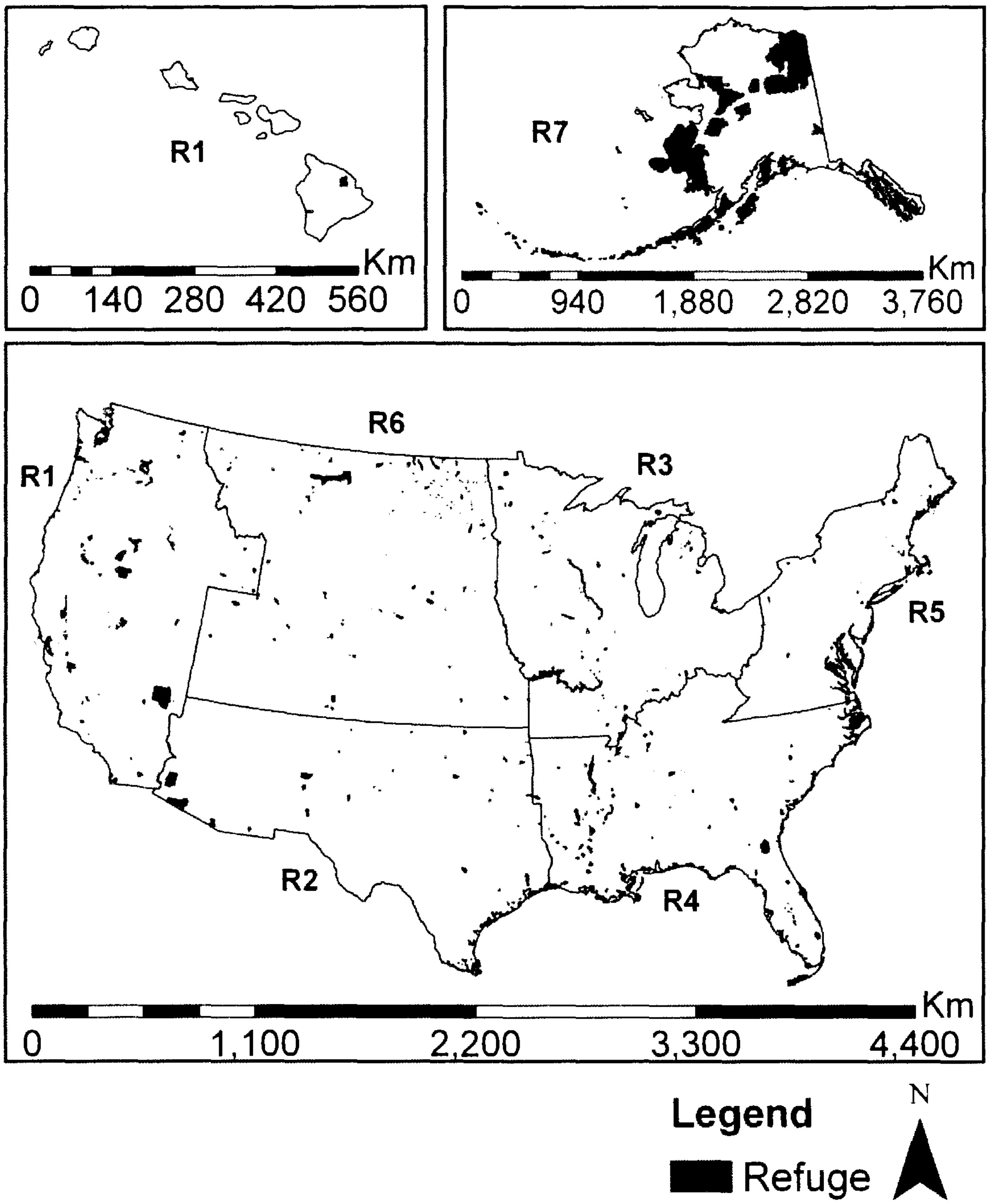

Figure 1. 2. Refuges in the National Wildlife Refuge System. Refuges occur in all 50 states. The 547 refuges are organized into seven regions (labeled on map).

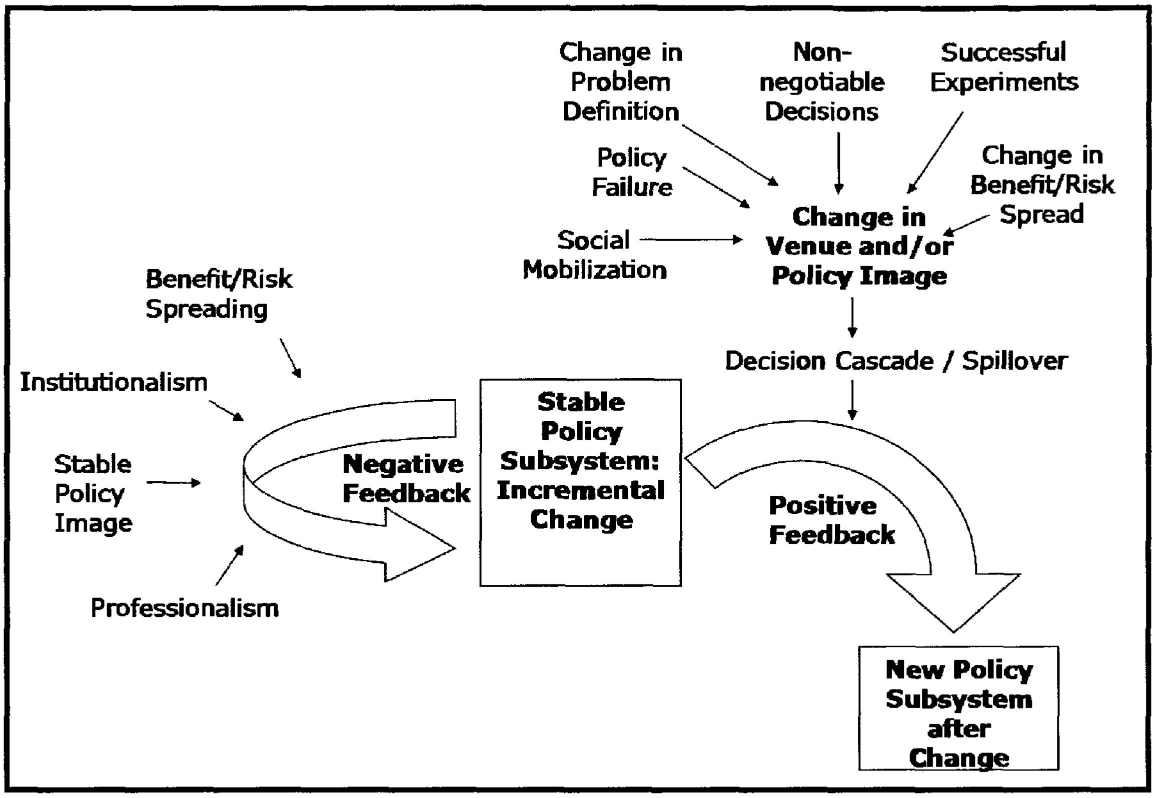

Figure 1. 3. Punctuated Equilibrium. Factors that affect policy stability through negative feedbacks and policy change through positive feedbacks. Factors that stabilize the policy image, like institutionalism and professionalism, will result in incremental change. However, when the policy venue or policy image changes, rapid restricting of the policy subsystem can occur.

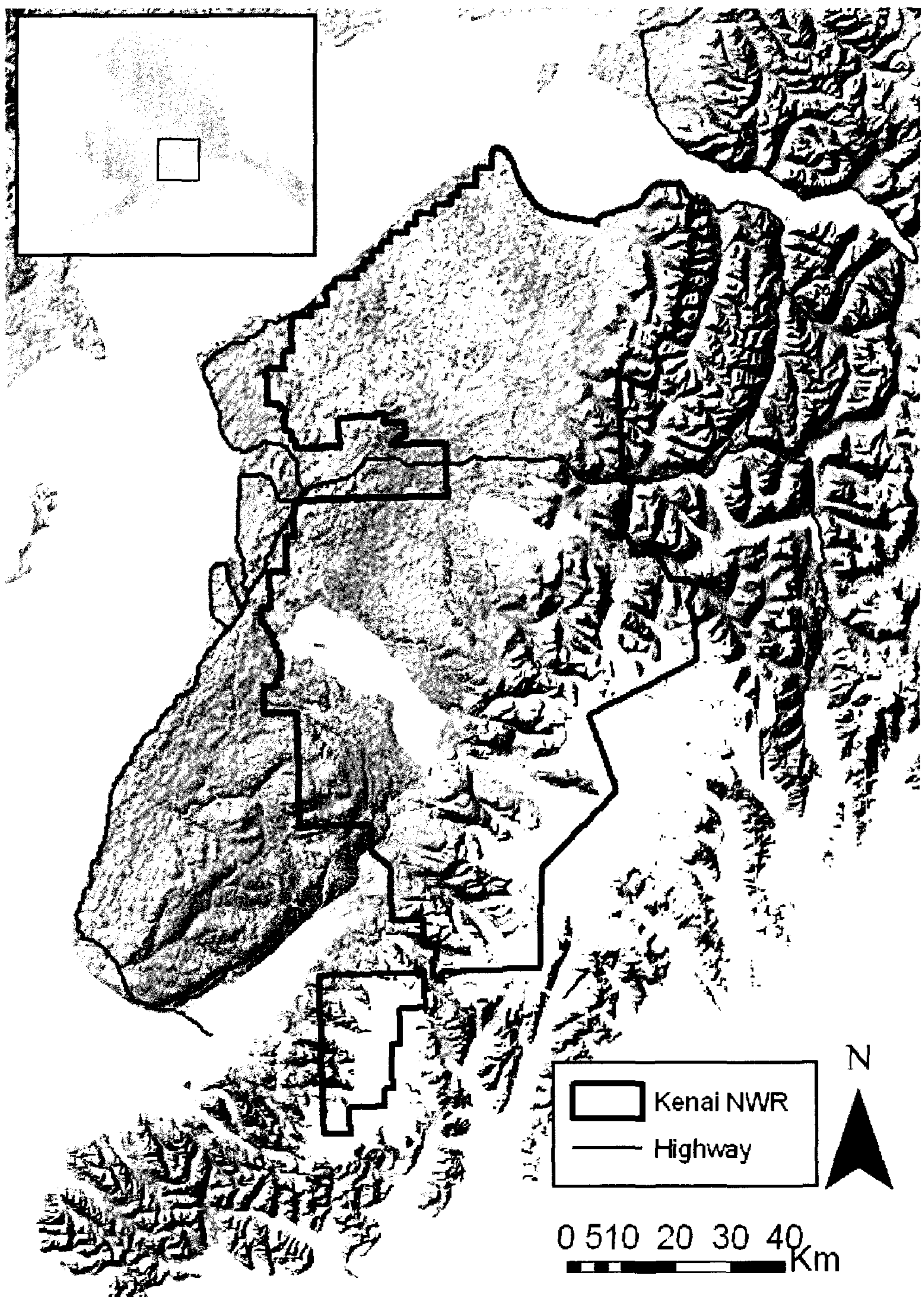

Figure 1. 4. Kenai National Wildlife Refuge. Refuge boundary located in south-central Alaska.

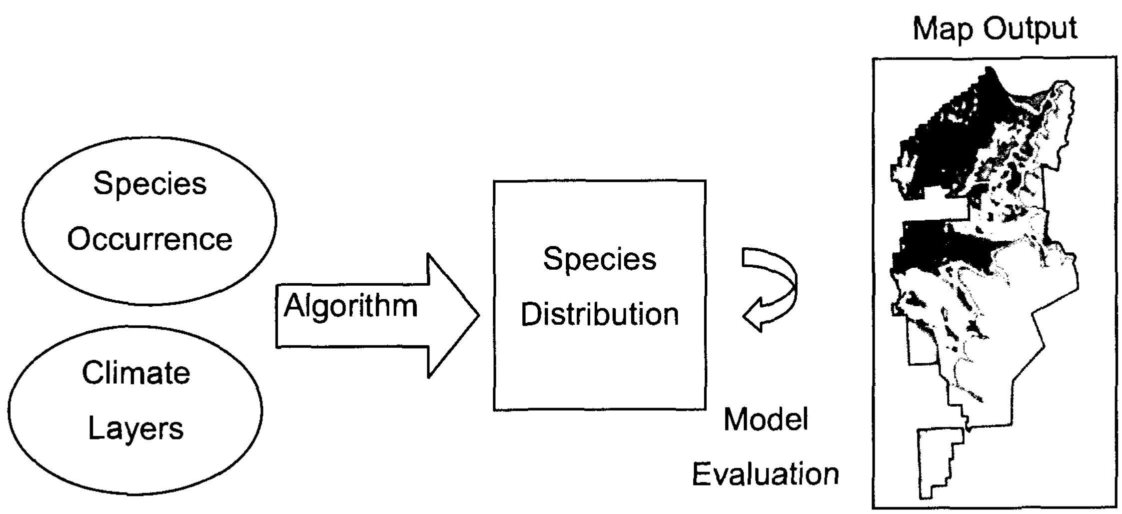

Figure 1. 5. Species Distribution Modeling Process. Flowchart representing the process of developing predictive species distribution models.

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Chapter 2 A Landscape-Scale Analysis of Climate-Change Risk and Ecosystem Resilience in the U.S. National Wildlife Refuge System

The characteristics of the land determined the facts as potently as the characteristics of the men who lived it.
Aldo Leopold, A Sand County Almanac, 1949

2.1 INTRODUCTION

National Wildlife Refuge System (NWRS) lands (Figure 2.1) were set aside to conserve fish, wildlife, and plants and their habitats for the benefit of present and future generations of Americans (Public Law 105 – 57). NWRS lands are vulnerable to ecosystem stressors associated with global climate change and these stressors threaten refuge resources. Ecosystem vulnerability can be defined as "*the degree to which these systems are susceptible to, and unable to cope with, the adverse impacts*" of climate change (IPCC 2007: 21).

Recent climate change has already affected physical and biological systems (Rosenzweig et al. 2007). The mean global surface temperature has increased 0.74°C since the early 1900s (Solomon et al. 2007). Documented changes attributed to climate change include sea-level rise, changes in snow, ice, and permafrost, and the warming of lakes and rivers (Rosenzweig et al. 2007). Temperature change affects species and ecosystems through distribution shifts, changes in phenology, and changes in abundance (Parmesan and Yohe 2003, Root et al. 2003, Rosenzweig et al. 2007). With accelerated warming, scientists expect increased extinction risks and corresponding changes to the functioning of terrestrial ecosystems (Fischlin et al. 2007). NWRS managers will need to respond to adverse impacts like extinction in order to protect biodiversity.

Both the rate of climate change and ecosystem resilience influence ecosystem vulnerability to climate change (Schneider et al. 2007). Resilience refers to the capacity of an ecosystem to adapt naturally to change (Fischlin et al.

2007). More specifically, the properties of resilience include the amount of change a system can undergo while maintaining a similar structure and function, the capacity of the system to self-organize without being forced by external factors, and the capacity of the system to learn and adapt (Carpenter et al. 2001). Resilient ecosystems can absorb disturbances and re-organize during times of massive transformation while maintaining the provision of ecosystem services (Chapin et al. 2004). Generally, humans affect an ecosystem's capacity to generate ecosystem services or to transform into a degraded state by changing biodiversity and disturbance regimes (Folke et al. 2004). Therefore, biodiversity is an ecosystem service that increases ecosystem resilience. However, biodiversity is non-renewable; once lost, biodiversity cannot be recovered.

For the NWRS, I used the concept of ecosystem vulnerability to develop a framework useful for national strategic adaptation planning. A variety of management approaches have been identified as useful for adaptation (Scott et al. 2008, Heller and Zavaleta 2009). The ecosystem vulnerability framework provides a strategic rationale for conceptually organizing adaptation options at the national scale. For national coordination, each refuge in the NWRS should focus on different management approaches for adaptation that are consistent with recent and projected climate change in the context of other ecological stressors. Conceptually, I defined four broad categories of adaptation goals based on climate change rates in the context of other ecological stressors (Figure 2.2). I conducted a GIS analysis of climate change impacts and ecosystem resilience of NWRS lands. Finally, I used the GIS analysis to organize refuges into the four adaptation goal categories to discuss the suites of management approaches most useful to meet these goals.

2.2 METHODS

I used data layers in ArcGIS 9.2 to compare refuges based on climate change rate and ecosystem resilience. I gathered GIS data from high-quality, public sources on the World Wide Web (WWW) to represent ecosystem vulnerability (Table 2.1 and Table 2.2). I calculated a Spearman rank correlation matrix for the climate change and resilience variables to ensure that all variables provide relatively independent measures of ecosystem vulnerability ($r_s < 0.7$; Appendix A).

In order to delineate NWRS lands, I used the legislative boundaries (USFWS 2001). The legislative boundaries include lands owned, lands with established management agreements or easements, and lands that have been authorized for future acquisition by Congress. Therefore, the legislative boundaries represent the planned future spatial distribution of refuge lands. I included only refuges in the 50 states of the United States, excluding lands in commonwealth nations and territories due to limitations in data availability. Refuges were digitized based on land status maps, planning documents, and legal surveys supplied by USFWS Realty and Refuge Planning programs.

2.2.1 Summarizing Climate Change Rate

Climate change includes temperature change and other corresponding effects like changes in weather patterns and sea level rise. Temperature change estimates have been compiled by several sources and these estimates vary spatially. Therefore, I analyzed both the rate of temperature change alone and a rate of climate change using three factors: (1) average temperature change, (2) precipitation change, and (3) sea level rise.

2.2.1.1 *Temperature Change*

I located sources for three independent, spatial estimates for temperature change (Table 2.1). I used Parameter-elevation Regressions on Independent

Slopes Model (PRISM) data to develop two fine-scale estimates (4-km^2 resolution) of recent temperature change: (1) change in mean annual daily minimum temperature and (2) change in mean annual daily maximum temperature. The PRISM algorithm interpolates spatial climate data through a process of weighting station data using expert knowledge. PRISM uses expert knowledge to reduce bias caused by sparse or unrepresentative stations (Daly et al. 2002). PRISM also uses expert knowledge to account for factors that affect climate at finer spatial scales (<10 km^2) such as terrain, coastal effects, rain shadows, cold-air drainage, and inversions (Daly 2006). PRISM summarizes the mean annual daily minimum and maximum temperature for each year beginning in 1900. In order to calculate temperature change, I averaged the mean annual daily minimum and maximum temperature surfaces for 90 years (1900 – 1989) to represent historic temperatures and the mean annual daily surface temperatures over the last 18 years (1990 – 2007) to represent recent temperatures. For both the minimum and maximum mean annual daily temperature, I subtracted the historic surface from the recent temperature surface to generate a change surface.

I used spatial, temperature-trend data provided by the Global Climate Change at a Glance spatial mapping tool (NCDC 2008) to generate a course-scale (5° or ~500-km^2) average temperature change trend estimate. To calculate the trend, the Global Climate Change at a Glance tool used average temperature estimates that were calculated yearly within each 5° grid cell. The GHCN-ERSST merged land, air, and sea surface temperature dataset (Smith and Reynolds 2005) provided filtered station data within each 5° cell to calculate the yearly average for each cell. Trends were estimated for each cell based on these yearly temperature estimates. I constructed the trend estimates beginning in 1971 because sampling stations were sparse prior to 1950, especially in Alaska (Peterson and Vose 1997). I also wanted to represent the strong warming trend that began in the 1970s (Smith and Reynolds 2005, Solomon et al. 2007).

For each of the three temperature change estimates, I averaged the pixels within each refuge's boarder. I could not generate estimates for the two PRISM datasets for refuges in Alaska and Hawaii because data are only available in the continental United States where climate stations are densely spaced. PRISM does not extend across large bodies of water. Therefore, PRISM data were not available for two ocean island refuges, Shell Keys National Wildlife Refuge and Thacher Island National Wildlife Refuge, or for West Sister Island National Wildlife Refuge on Lake Erie. I calculated descriptive statistics (mean, SE, median, and range) to summarize the average temperature change estimates across refuges. In order to compare refuges, I ranked the refuges for each of the temperature range estimates based on the absolute value of each temperature change estimate. I scaled the refuge rank into a percentage by dividing the rank by the total number of refuges ranked to generate an index. For refuges with PRISM data, I averaged the index for the three temperature change estimates to calculate an index of temperature change for each refuge in the continental United States. For Alaska, Hawaii, and the three island refuges, only the GHCN-ERSST temperature trend estimates were used. The temperature change index ranged from 0 to 100; larger numbers indicate larger changes to temperature.

2.2.1.2 *Climate Change*

In order to provide a more inclusive estimate of climate change, I also indexed refuges based on temperature change, precipitation change, and potential sea level rise (Table 2.1). I used the temperature change index calculated in the previous section. I used PRISM data to create a spatial estimate precipitation change. I calculated the 90-year historic annual precipitation by averaging the annual precipitation from 1900 to 1989. I calculated recent annual precipitation by averaging the annual precipitation from 1990 to 2007. The precipitation change surface represents the difference between the historic and recent average annual precipitation. For refuges with PRISM data, I averaged the precipitation-change surface pixels within each refuge. I ranked the absolute value of the average refuge precipitation change and scaled the ranking from 0 to 100.

I used the Pythagorean Theorem to summarize the potential for sea level rise as a function of distance to the coast and elevation. For most refuges, I measured the Euclidean distance to the nearest coastline from the center of each refuge. For 45 island refuges, I measured the Euclidean distance from the center of the largest island to the nearest coast. I used the maximum elevation within the refuge boarders. I ranked the distance to nearest coastline and scaled from 0 to 100.

I averaged the scaled refuge rankings for average temperature change, precipitation change, and potential sea level rise to create an index of climate change rate. Larger index values indicate faster rates of climate change.

2.2.2 Summarizing Ecosystem Resiiience

Finally, I indexed the refuges based on estimated resilience. I used refuge size, road density, and elevation range as ecosystem resilience variables (Table 2.2). I calculated the refuge size (km^2) from the refuge boundary layer. Refuge size is a good indicator of species numbers because large areas contain and maintain more species (Foreman 1995). I estimated road density (m/ha) in a 10-km buffer around each refuge as an indicator of the potential for species dispersal. Roads increase mortality and avoidance behaviors causing a barrier effect that subdivides populations (Forman and Alexander 1998, Trombulak and Frissell 2000). In addition, roads can reduce resilience through habitat fragmentation, carbon emissions, changes in fire ignition rates, species extinction, introduced species and other disturbances (Cumming et al. 2005). I also used the northern and southern extent of each refuge to calculate latitudinal range and the minimum and maximum elevation to calculate the elevation range. Both latitudinal and elevation range influence the potential for species migration along climatic gradients (McNeely 1990). However, I did not include latitudinal range in the analysis because it is highly correlated with refuge size (r_s = 0.807).

I ranked refuges from small to large for refuge size and scaled the refuge rank into a percentage by dividing the rank by the total number of refuges ranked. I ranked refuges from high to low for road density and scaled the ranking. Finally, I ranked and scaled refuges from small to large for elevation range. I averaged the scaled ranking for refuge size, road density, and elevation range to create a resilience index. Lower values of the resilience variable indicated refuges with higher levels of ecosystem stressors and therefore, reduced ecosystem resilience.

2.2.3 Evaluating Ecosystem Vulnerability

I separated the refuges into four adaptation categories based on ecosystem vulnerability (Figure 2.2). I used the scaled refuge rank, which ranges from 0 to 100, to delineate these categories. I used the scaled rank of 50 to delineate between high and low. I also separated refuges based on the climate change rate and resilience rank.

2.3 RESULTS

The NWRS includes 527 refuges in the United States. Refuges encompass approximately 456,844 km^2 (Figure 2.1). Refuges were distributed across all 50 states.

2.3.1 Climate Change Rate

2.3.1.1 *Temperature Change*

On NWRS lands, mean annual daily minimum temperatures departed more from the 90-year average than did the mean annual daily maximum temperature (Table 2.3). The southeastern United States exhibited slower temperature change rates than other parts of the country (Figure 2.3). However, the high spatial resolution of the PRISM data displayed small pockets of cooling in regions that otherwise were shown as warming (Figure 2.4). These general trends of increased warming with latitude and localized temperature trends are well documented (Solomon et al. 2007).

When the scaled temperature change ranks were averaged, 36% of refuges classified with high temperature change rates and 41% of refuges classified with low rates would be classified into those categories based on all three of the temperature change estimates. Other refuges would be grouped differently based on one or two of the temperature change estimate ranks (Figure 2.5). For example, clusters of refuges on the East Coast and along the Mississippi River were classified as having low temperature change rates overall even though mean annual daily maximum temperature change rates were high. The 262 refuges classified with high temperature change rates averaged a 1.07°C (*SE* =0.026) increase in mean annual daily minimum temperature, a 0.54°C (*SE* = 0.023) increase in mean annual daily maximum temperature, and a 0.27°C/decade (*SE* = 0.006) regional trend. The 265 refuges classified with low temperature change rates averaged a 0.50°C (*SE* =0.022) increase in mean annual daily minimum temperature, a 0.04°C (*SE* = 0.020) increase in mean annual daily maximum temperature, and a 0.14°C/decade (*SE* = 0.004) regional trend. St. Marks National Wildlife Refuge, located on Florida's Gulf Coast, was subject to the lowest levels of temperature change with -0.12°C *decrease* in mean annual daily minimum temperature, a 0.06°C increase in mean annual daily maximum temperature and 0.03°C/decade regional trend. The Arctic National Wildlife Refuge, on the North Slope of Alaska, was the fastest changing with a 0.69°C/decade regional trend.

2.3.1.2 *Climate Change*

On average, NWRS lands have been slightly wetter over the past 18 years than the 90-year average (Table 2.3). Precipitation change is spatially variable with locally wetter and dryer areas (Figure 2.6). Siletz Bay National Wildlife Refuge on the central Oregon Coast had the largest drop in rainfall with an 18-year precipitation average that was 106 mm less than the 90-year average. Flattery Rocks National Wildlife Refuge, near the Olympic Peninsula in Washington, was experiencing the greatest increase in rainfall with a 280 mm increase. Refuges classified with high climate change rates had an average increase of 73.8 mm (*SE* = 3.71). Refuges classified with low climate change rates had an average increase of 28.4 mm (*SE* = 1.86).

The potential for sea level rise was measured using distance to the coast. When only sea level rise was considered, the median sea level distance of 290 km provided the break between refuges classified with high or low climate change rates. The average distance to coast for refuges classified with high climate change rates was 179 km (*SE* = 19.7). For refuges classified with low climate change rates the average distance was 711 km (*SE* = 28.0). Shell Keys National Wildlife Refuge, a small, shifting islet composed mainly of shell fragments, was the refuge with the highest potential for sea level rise.

2.3.2 Ecosystem Resilience

I measured ecosystem resilience using refuge size, the road density in the matrix surrounding the refuge, and the elevation range within the refuge. Most refuges in the NWRS are small with the exception of Alaskan refuges (Table 2.4). Based on area alone, the median refuge size of 35.3 km^2 provided the break between refuges classified with high and low resilience. When all resilience measures were included, refuges classified with high resilience had an averaged 1734 km^2 (*SE* = 540.3), but the median size was only 106 ha. Refuges classified with low resilience average 29 km^2 (*SE* = 4.0), but the median size was only 8.1 km^2. Mille Lacs National Wildlife Refuge, two small lake islands in Minnesota, was the smallest refuge with less than 0.004 km^2.With over 106,500 km^2, Yukon Delta National Wildlife Refuge was the largest refuge because the acquisition boundary included an ocean buffer around Nunivak Island. If only terrestrial area was included, Arctic National Wildlife Refuge was the largest refuge in the NWRS.

In general, road density in North America decreased from east to west and from south to north. The 259 refuges classified with high resilience averaged 10.3 m of road/ ha (*SE* = 0.40) in the surrounding landscape. The 268 classified with low resilience averaged 17.1 m/ha (*SE* = 0.73). John Heinz National Wildlife Refuge at Tinicum, an urban refuge near the Philadelphia International Airport, had the highest road density with 78.1 m/ha of road in the surrounding landscape.

Most refuges do not have a large elevation range within the refuge boundary (Table 2.4). Refuges classified with high resilience averaged a 218 m (*SE* = 27.1) elevation range, but the median was only 55 m. Refuges classified with low resilience averaged only 17 m (*SE* = 1.5) with a median of 13 m.

2.3.3 Ecosystem Vulnerability of the National Wildlife Refuge System

Ecosystem vulnerability to climate change depends on both the rate of change and the resilience of the system. Therefore, I categorized all refuges into four groups within different adaptation goals (see Figure 2.2) based on each refuge's relative climate change (or temperature change) rate and resilience (Figure 2.7 and Appendix B). Refuges with fast temperature change and high resilience were located in Alaska and the western United States. When precipitation and sea level rise were included, refuges with fast climate change rates and high resilience in the continental United States shifted toward the coast.

I categorized many refuges in southeastern United States as having slow rates of temperature change and high resilience. When sea level rise and precipitation change were included in the analysis, refuges categorized with slow climate change and high resilience were more scattered across the interior of the continental United States.

When temperature change was considered, refuges with fast rates of change and low resilience were concentrated in the north-central United States, the northeastern coast, and the Pacific coast. However, refuges categorized with fast climate change rates and low resilience shifted to coastal areas when sea level rise and precipitation change were included in the analysis.

Refuges with slow rates of climate change and low resilience were mainly located in the southeast United States, the north central United States and Hawaii. Fewer refuges in the north central United States and more refuges on the East Coast were included in this group when temperature change alone, without sea level rise and precipitation change, was considered.

2.4 DISCUSSION

Ecosystem vulnerability provides a framework to conceptualize categories of adaptation goals that are useful for national strategic planning (Figure 2.2). Climate change has the potential to cause mass extinctions; 20 – 30% of all species will face an increasingly high risk of extinction as global mean temperatures exceed 2 to 3° C above pre-industrial levels (Fischlin et al. 2007). Given the NWRS focus on maintaining biodiversity, the overall adaptation goal should be to minimize species extinction. Refuges within the NWRS are experiencing various levels of climatic change that operate in the context of other ecological stressors (Scott et al. 2008). A national strategic adaptation plan will need to spatially and temporally coordinate refuges based on current conditions and likely future conditions. Recognizing that individual refuges will have different adaptation goals will help managers identify and prioritize relevant management approaches based on the larger NWRS context.

Minimizing species extinction is not the mirror image of maintaining biodiversity. Biodiversity is a mega-concept, not a specific ecological attribute. Therefore, maximizing biodiversity is not a clear enough objective to be useful for broad decision-making frameworks. Biodiversity must be defined in each management context which requires value judgments about what components of biodiversity are most important (Failing and Gregory 2003). Specifically, defining biodiversity includes the consideration of the spatial scale, the relative importance of species richness versus evenness, and the temporal scale. For example, maintaining biodiversity within a refuge boundary could be interpreted as meaning maximizing overall species richness or as increasing the population of a rare species. Minimizing species extinction provides a simple objective of maintaining as many species as possible in habitats outside of cryogenics, seed-banks, and zoos. Analyzing the extinction-risk of multiple species provides explicit objectives that can be used in decision-theoretic approaches to conservation planning (Nicholson and Possingham 2006)

Adaptation refers to "*the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities*" (Parry et al. 2007: 6). Animal and plant species can adapt to climatic changes through migration to suitable habitat, phenological responses, and morphological or physiological change (Noss 2001). However, adaptations by animal and plant species are limited by life history traits, dispersal abilities, genetic properties, and landscape context (Root and Schneider 2001, Parmesan 2006). Humans can implement a variety of adaptation options, ranging from technological solutions to policy change (i.e. modification of behavior and practices), in order to reduce ecosystem vulnerability and increase the ability of other species to adapt naturally (Parry et al. 2007). For the remainder of this paper, I am concerned with adaptation strategies that can be employed by managers in the NWRS to reduce ecosystem vulnerability and minimize extinction.

Within the past 20 years, various management approaches that are useful for adapting to climate changes have been suggested in the scientific literature (Heller and Zavaleta 2009). In an assessment for the NWRS, adaptation options were organized by whether they occurred primarily within or outside of refuge boundaries (Scott et al. 2008). Inside refuge borders managers have the opportunity to utilize intensive management like prescribed burning, establishing populations of climate suitable plants and animals, predator control, and feeding programs. Outside refuge borders managers could use partnerships, easements, and other ownership regimes to design a network of reserves, maintain connectivity, and manage hydrology with a variety of activities not excluding engineered structures. Although useful, categorization based on land ownership does not provide situational guidance.

Heller and Zavaleta (2009) organize adaptation options based on whether they are risk adverse or risk tolerant. Risk adverse options encompass precautionary or robust actions that included tested conservation practices like reducing non-climatic stressors, protecting more habitat, and restoration. Risk tolerant activities are anticipatory and therefore, deterministic and risky because they work to mold future conditions based on expectations. Risk tolerant activities utilize forecasts of future conditions to engage in management activities based on model outcomes, like translocation and habitat manipulation. Conceptualizing adaption options as risk adverse or risk tolerant is insightful because it captures managing for future conditions as an alternative goal.

However, the risk adverse strategies do not explicitly define whether the goal is maintaining historical conditions or facilitating transitions to future conditions. Conceptualizing adaptation options as reactionary or anticipatory organizes options based on the tension between managing for historic conditions and managing for future conditions (Easterling III et al. 2004). The goal of reactionary adaptation strategies is to reduce climatic stressors in order to maintain historic conditions. Reactionary strategies include engineered structures to maintain sea-level or hydrologic regimes, supplemental feeding programs to counteract phenological mismatches, restoration initiatives, and other intensive management techniques. Reactionary strategies will be best applied over the short-term as a bet hedging strategy while the uncertainty about future conditions is high and to give species of concern time to transition to future conditions.

Anticipatory strategies manage for likely and desirable future conditions. Anticipatory strategies can focus on increasing the likelihood of systems adapting naturally with efforts like increasing landscape connectivity for movement. Alternatively, anticipatory strategies can focus on transitioning an ecosystem to a desirable future condition that is compatible with climatic conditions. Desirable future conditions imply an active choice by managers and include options like translocating suites of plant and animal species or changing the identity of species of concern for a refuge.

2.4.1 Adaptation Goals Based on Ecosystem Vulnerability

Understanding when to apply reactionary or anticipatory strategies will depend on the landscape context. For example, engaging in restoration in areas where climatic variables have undergone directional change will set the system up for a rapid ecological shift after disturbance (Scheffer et al. 2001). Therefore, understanding how ecosystem vulnerability, in terms of climate change rates and resilience, varies spatially will be essential for developing a coordinated, national adaptation plan for the NWRS. The Alaska and the central flyway case study, in an assessment of adaptation options for the NWRS, is an example where landscape context is crucial for effective management with climate change (Griffith and McGuire 2008). Along the central flyway, spatial heterogeneity in the magnitude of climate and other ecological stressors leads to differences in suggested appropriate adaptation options. For the national scale, I conducted a GIS analysis of the ecosystem vulnerability of refuge lands. I developed a framework based on ecosystem vulnerability to sort refuges into four categories with different adaptation goals (Figure 2.2). The adaptation goal of each refuge defines the suites of adaptation options that are most suitable given the landscape context.

2.4.1.1 *Experiments in Natural Adaptation*

Refuges with high resilience and fast rates of climatic change can serve as experiments in natural adaptation within the NWRS. These areas present an opportunity to study how ecosystems naturally adapt to directional change. These refuges can also serve as case studies to test whether anticipatory management can facilitate the non-linear and complex responses of ecosystems. Increased monitoring in these refuges will also be necessary to provide the background and context to understand how climatic change affects ecosystems. Context monitoring, which tracks a suite of variables that are not related to specific management actions, will be appropriate (Busch and Trexler 2003). Although context monitoring has been criticized for being inefficient and unfocused (Nichols and Williams 2006), climate change will likely result in unexpected ecological changes that may not be captured by narrowly designed monitoring programs. These areas may also present an opportunity to form partnerships to protect landscape integrity and connectivity in regions where development has not reduced conservation options.

My analysis identified regions, like Alaska and the western United States, with fast rates of climate change and high ecosystem resilience (Figure 2.7). Alaskan refuges may provide the best opportunity to allow ecosystems to adapt naturally because they encompass large areas within a landscape matrix that is relatively intact. However, Alaska is also undergoing climatic changes that are more rapid and of larger magnitude than other parts of the United States (ACIA 2005). Therefore, over the short-term, reactionary management activities may be justified to minimize species extinctions due to the rapid rates of change.

2.4.1.2 *Refugia*

Refuges with slow rates of climatic change and high resilience will serve as refugia for current ecological conditions, and their species assemblages, within the NWRS. If not already available, managers should prioritize inventory programs to document which species are represented in these areas. Management activities can be reactionary and serve to maintain historic conditions. Refugia will become potential sources of biodiversity for other transitioning refuges, so managers should use standard conservation principles to ensure that the reserve size and connectivity are adequate to ensure refugia viability. In addition, refugia should be assessed for their potential to serve as stepping stones to other refuges that are transitioning more rapidly with climate change. To this end, partnerships and other collaborative land ownership regimes can help to maintain connectivity and other landscape qualities that provide resilience. In this analysis, high resilience is relative and based on a ranking of the resilience of other refuges within the NWRS. However, in agreement with Scott et al. (2004), my analysis indicates that most refuges are small islands within an anthropogenic matrix. In addition, my analysis indicates that most refuges are undergoing some directional climatic change to climatic variables. Therefore, modeling, monitoring, and other studies are necessary to confirm that these areas are truly serving as refugia.

2.4.1.3 *Facilitate Transitions*

Refuges with fast rates of climate change and low resilience will require management activities to facilitate transitions. These areas have a high probability of ecological reorganization, so managers need to be aware of probable future climatic conditions and the species assemblages that could be supported in these new conditions. In these areas, restoration to historic conditions may be unlikely or impossible (Hobbs and Harris 2001, Choi 2007). Management activities that facilitate transitions must be anticipatory, but many require some reactionary strategies in the short term. Over the long-term, these refuges will benefit from anticipatory management approaches that increase the likelihood of natural adaptation through increasing connectivity and reducing other ecological stressors. However, these refuges will also likely benefit from anticipatory management, like habitat manipulation and introducing new species assemblages, which facilitate transitions to desirable ecological conditions that are compatible with future climatic conditions. While planning transitions, managers should analyze the potential for these refuges to serve as stepping stones to other areas. In the short term, reactionary adaptation options may be an important precautionary strategy when future conditions are uncertain or when rare species would benefit from additional time to cope with changes. Reactive adaptation options include engineered structures to limit sea water inundation, feeding programs to reduce food shortages caused by phenological shifts, habitat manipulation toward historic conditions, and altering water flow to reduce drought conditions. Reactionary adaptation options will be costly if they require intensive management practices or engineered structures. In addition, these adaptations are unlikely to be viable in the long-term solutions as climatic conditions continue to shift. Refuges with high levels of anthropogenic stressors (low resilience) may have difficulty identifying the effects of climate change impacts because these effects will be operating synergistically. Therefore, identifying regions with fast rates of climate change could help to identify refuges where interactions with other stressors are important to consider.

2.4.1.4 *Ecosystem Maintenance*

Refuges with slow rates of climate change and low ecosystem resilience will benefit from management approaches aimed at ecosystem maintenance. Adaptation options will be reactionary with the goal of maintaining or restoring historic conditions. Conservation biologists have invested more time developing strategies to reduce other ecosystem stressors not related to climate (Fischlin et al. 2007). Refuges working toward ecosystem maintenance will benefit from these standard conservation approaches that manage anthropogenic stressors like fragmentation, land-use change, invasive species and over-exploitation. As these refuges are under anthropogenic pressure, managers should ensure that the plants, animals, and habitats represented are redundant within the NWRS. In addition, managers should evaluate the potential for these refuges to serve as stepping stones for other refuges that are transitioning due to climate change or as population sources to sustain diversity at the local scale.

2.4.2 Temporal Scales and Uncertainty

My analysis focuses on the importance of the spatial heterogeneity of ecosystem vulnerability to climate change in developing a strategic adaptation plan. However, there is also a temporal component to climate adaption. The data used here to characterize rates of climate change are historical datasets.

Regional planning may also be conducted using spatial projections of future warming or other ecological changes. For example, environmental domains, consisting of topographic, edaphic, and climate attributes, have been mapped and projected to 2100 in order to map areas likely to undergo environmental change (Saxon et al. 2005). The Natural Conservancy, in conjunction with the U.S. Forest Service and Oregon State University, are calculating spatial probabilities for vegetation shifts using climate projections that can be used to identify refugia and transitional habitats (Scott et al. 2008). Lawler et al. (2009) produced a spatial analysis of species turnover based on future climate change projections.

Considering forecasts of future conditions will be beneficial for management. However, uncertainty increases as the timeframe of a projection increases. Adaptation strategies are more likely to respond to forecasts over shorter timeframes.

2.4.3 Spatial Scale of Analysis

In this analysis, I compared the ecosystem vulnerability of all refuges within the United States. I ranked refuges for comparison in order to synthesize multiple variables with different units of measurement. However, the ecosystem vulnerability framework provides a planning rationale that could be applied at other spatial scales besides the entire NWRS. For example, refuges could be ranked independently by flyways, biological ecoregions, or regional boundaries. Comparing refuges from smaller spatial scales may ensure that the range of adaptation goals are represented within smaller planning units.

2.4.4 Analysis Caveats

The ecosystem vulnerability framework provides a rationale for organizing refuges based on categories of adaptation goals. The resulting management strategies that are identified can be modified as new and better data and analysis techniques provide new insight into where individual refuges fit into the framework and as managers learn from the changes that they observe in their refuges in response to management. Managers and other scientists must continue to define the best strategies to characterize ecosystem vulnerability in terms of climate change rates and resilience. Data availability and variable choice strongly affect the outcome of ecosystem vulnerability analyses. Many factors not represented in my analysis, like snowpack, species assemblages, and hydrological regimes, also affect ecosystem vulnerability and could be added to the analysis where data are available.

I ranked refuges within the NWRS to provide a relative measure of climate change and resilience for each refuge. Ranking allowed refuges to be compared and sorted into four categories of ecosystem vulnerability. However, a refuge categorized as being highly resilient when compared to other refuges may still be vulnerable to high levels of anthropogenic stressors. Most refuges are small, isolated, and embedded in developed landscapes (Scott et al. 2004). Similarly, refuges categorized by low levels of climate change are still subject to directional, global climate change.

I used individual refuges as the primary unit of analysis. However, some refuge management operates across the refuge unit. For example, migratory bird refuges work together to connect migration corridors; and many refuges are embedded in a larger complex of refuges. Refuge management is also strongly dictated by the establishment purpose of the refuge (Fischman 2003). My measures of ecosystem resilience may not be applicable to all refuge purposes. Refuges established for waterfowl production may plant crops to supplement waterfowl food supply. Increasing resilience by converting this type of farmland to other vegetation types may not be a viable management option in the context of local management objectives. Refuges established for endangered species will be more likely to implement intensive management options to reduce climate impacts and ensure that species are able to adapt to new conditions without facing extinction. In addition, refuges with endangered species will need to consider lands outside refuge boundaries. Endangered species that are currently protected may only be able to survive in areas outside of protected areas as the climate changes. (Peters and Darling 1985, Root and Schneider 2001, Inkley et al. 2004). Efforts should be made to forecast where the climatic conditions needed by rare or endangered species will occur in the future so conservation easements can be planned (Hannah et al. 2002). This strategy may require more flexible approaches, like reserves that are not static, be used because ecological conditions may change rapidly (Chapin et al. 2004). Species with limited dispersal options due to habitat fragmentation or that cannot keep pace with rapid change due to physiological constraints may need to be moved to new habitat (Hunter 2007, McLachlan et al. 2007).

At regional scales, additional variables and new datasets may be more insightful. Other important impacts may require analyses conducted at smaller spatial scales. Finally, managers and biologists in the individual refuges will likely have additional criteria that are pertinent to understanding climate change and resilience within their geographic region.

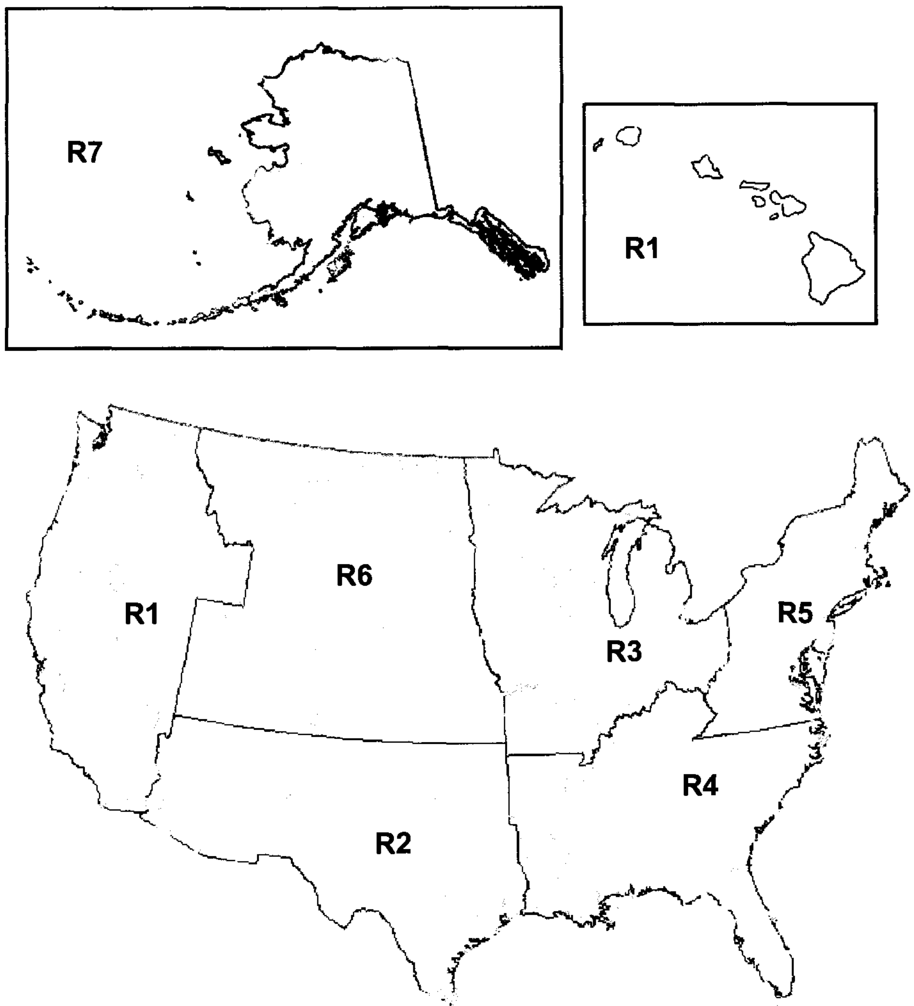


Figure 2. 1. Refuge Lands. Lands owned, managed, or approved for acquisition by the National Wildlife Refuge System. Refuge administration is organized by seven spatlal regions (labeled on map). Alaska and Hawaii are not to scaie

Climate Change Rate ↓ / Resilience →	LOW	HIGH
HIGH	**Facilitate Transitions** • Identify future habitat conditions that are likely and desirable. • Actively transform habitat. • Provide stepping stones to assist migration both out and into refuge. • In the short term, while uncertainty is high, aggressively provide species maximum opportunities to adapt.	**Experiments in Natural Adaptation** • Utilize opportunity to study how ecosystems naturally adapt • In the short term, management activities, may facilitate transformation when necessary or as habitat is needed. • Establish partnerships to maintain landscape qualities that provide resilience to refuge, especially connectivity.
LOW	**Ecosystem Maintenance** • Ensure redundancy of habitat types exists within the System. • Analyze potential of refuge to serve as stepping stone for areas that are transitioning. • Work to increase resilience by reducing non-climate stressors.	**Refugia** • Inventory species represented in refuge. • Assess potential of refuge to become a source for transitioning refuges. • Establish partnerships to maintain landscape qualities that provide resilience to refuge, especially connectivity.

Figure 2. 2. Matrix of Adaptation Goals. Four categories of adaptation goals identified based on ecosystem vulnerability framework. Climate change rate and resilience are the components of ecosystem vulnerability. Management approaches differ depending on the goal. Refuges are organized into these categories based on GIS analysis.

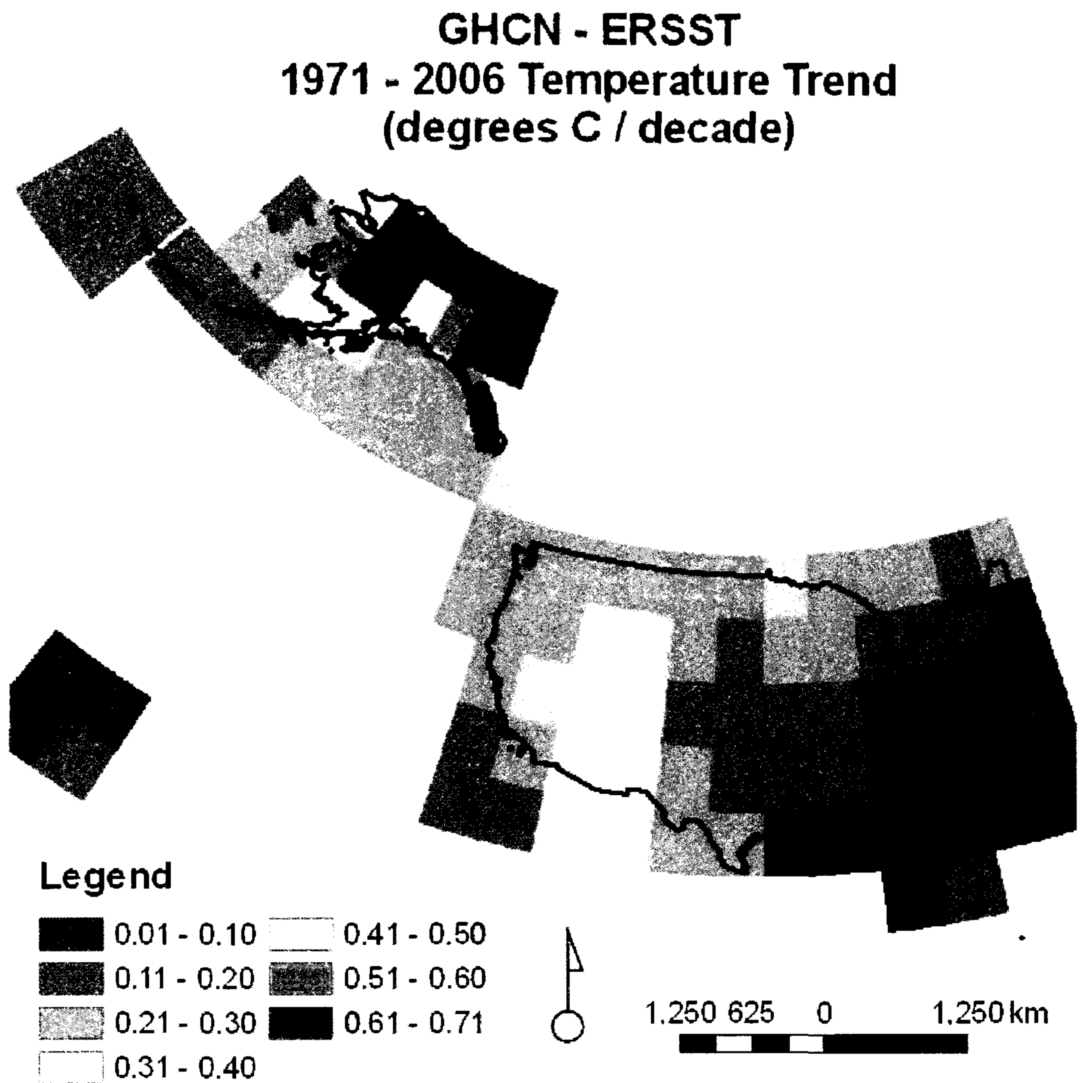
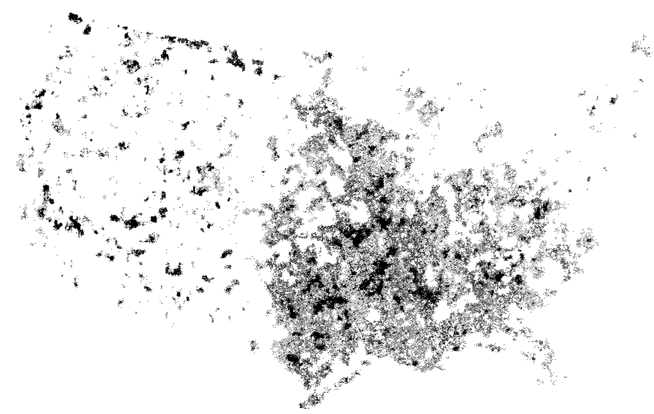


Figure 2. 3. Regional Temperature Change. Temperature trend estimates generated from the GHCN - ERSST dataset. Dataset consolidates weather station data within each 5° lat/long cell. Trends generated by the National Climatic Data Center's (NCDC) Global Climate at a Glance spatial mapping tool. Map displayed in Albers Equal Area projection.

Change in Mean Annual Daily Maximum Temperature (degree C)



Change in Mean Annual Daily Minimum Temperature (degree C)

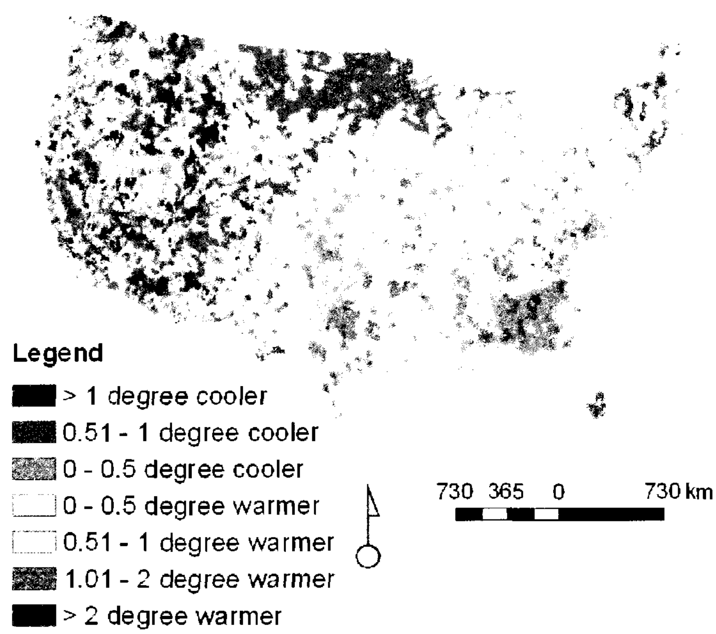


Figure 2. 4. Minimum and Maximum Temperature Change. Change in mean annual daily minimum and maximum temperature estimated by subtracting the historic 90-year normal values for each 4-km^2 pixel from the most recent 18-year normal (1990 – 2007). Station data were interpolated by the PRISM group at Oregon State University

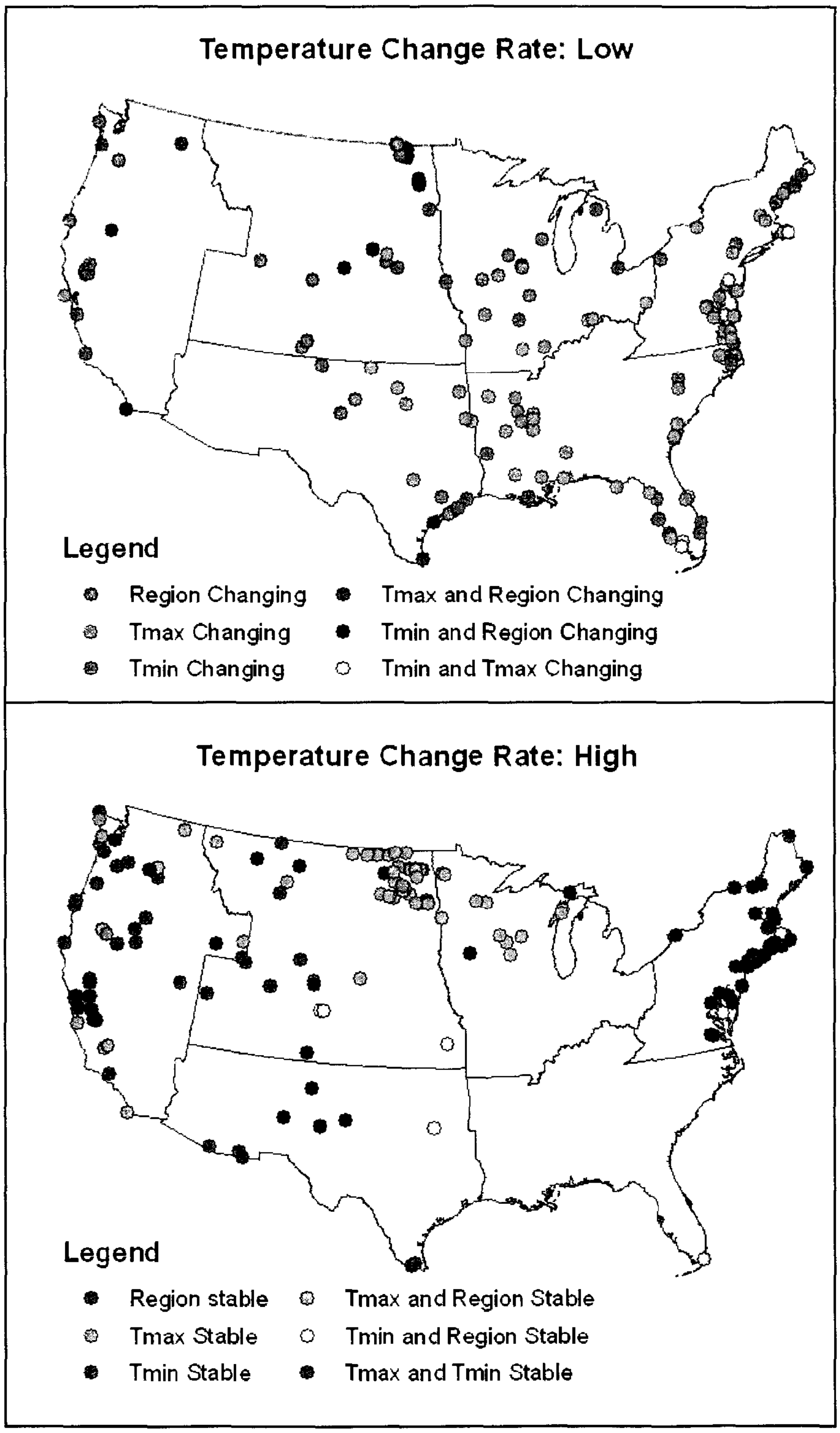


Figure 2. 5. Temperature Change Classification. Center-points of refuges indicate how three temperature change rate estimates differed based on the high/low classification.

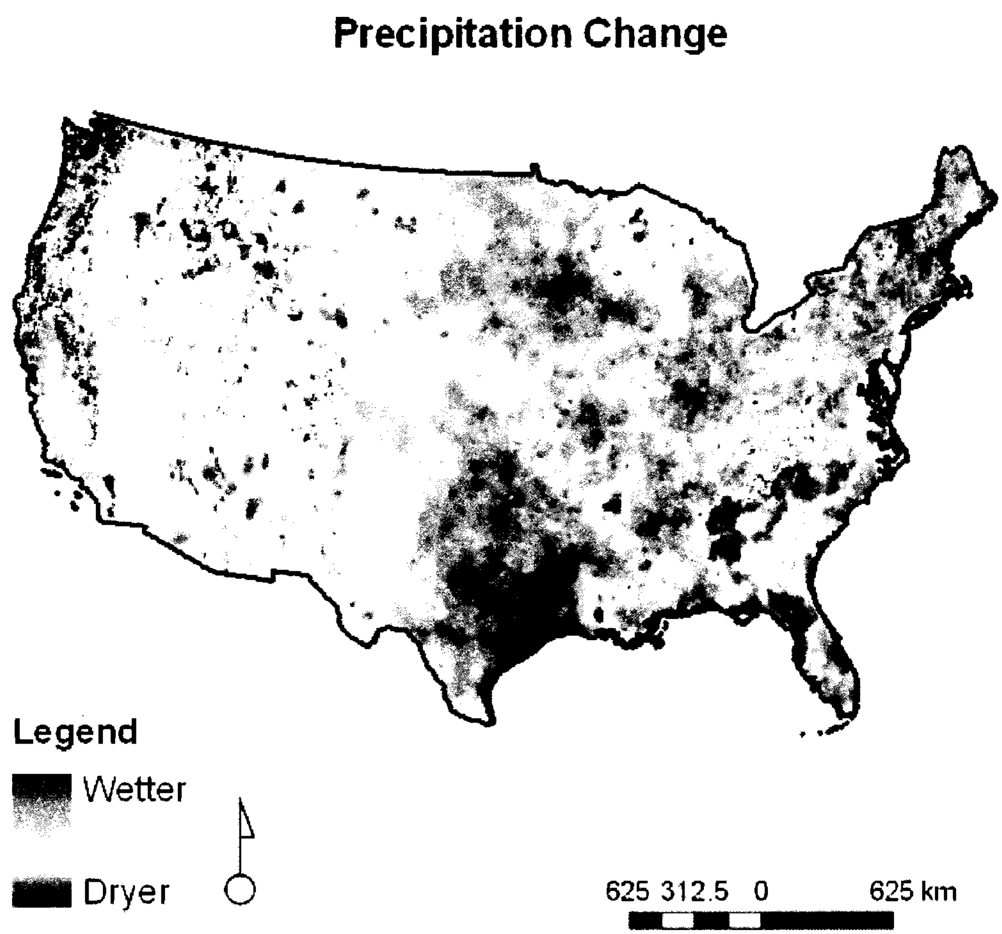


Figure 2. 6. Precipitation Change. Precipitation change (mm) calculated by subtracting the 90-year precipitation normal from the 18-year recent average precipitation from 1990-2007. Data provided at a 4-km^2 resolution by the PRISM group at Oregon State University.

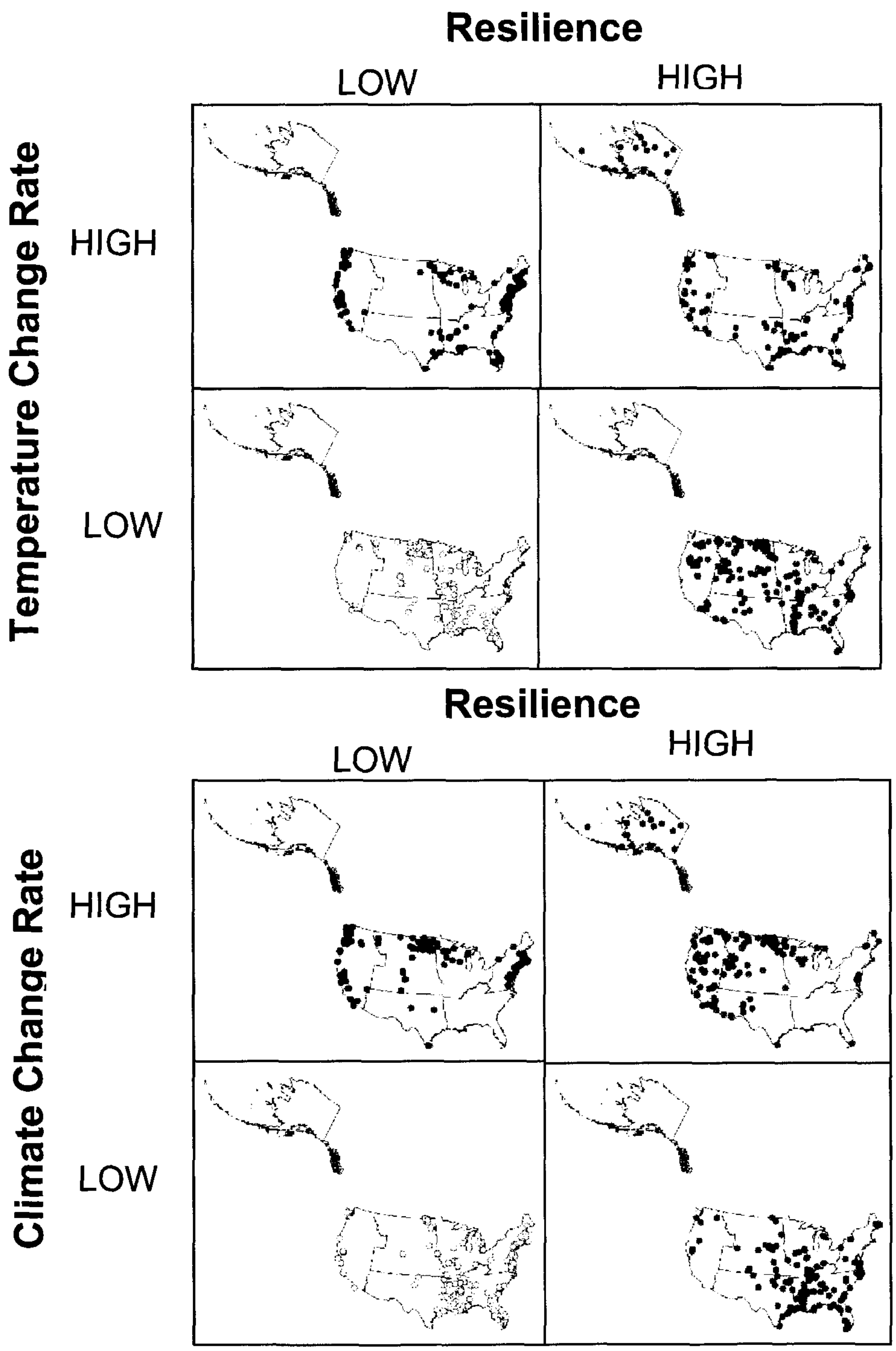


Figure 2. 7. Refuges Classified by Ecosystem Vulnerability. Refuges are grouped into four ecosystem vulnerability categories based on ranked climate change (or temperature) and resilience. Refuges marked by center-point.

Table 2. 1. Climate Source Information. Spatial datasets used to estimate climate change for the GIS analysis of lands in the National Wildlife Refuge System.

Climate Change Variable	**Temporal Extent of Source Data**	**Spatial Resolution of Source Data**	**Spatial Extent of Source Data**	**Citations for Distribution of Source Data**
Mean Annual Daily Minimum Temperature Change (°C)	1900 – 2007	4 km^2	Contiguous United States	(PRISM 2007b)
Mean Annual Daily Maximum Temperature Change (°C)	1900 – 2007	4 km^2	Contiguous United States	(PRISM 2007a)
GHCN – ERSST Temperature Trend (°C/decade)	1971 – 2006	5° latitude /longitude (~500-km^2)	Global, but dependent on station density.	(NCDC 2008)
Precipitation Change (mm)	1900 – 2007	4 km^2	Contiguous United States	(PRISM 2007c)
Sea Level Rise (m)	Static	500 m^2	North America	(USGS 1999, National Atlas of the United States 2005)

Table 2. 2. Resilience Source Information. Spatial datasets used to estimate resilience for the GIS analysis of lands in the National Wildlife Refuge System.

Resilience Variable	Temporal Extent of Source Data	Spatial Resolution of Source Data	Spatial Extent of Source Data	Source Data
Refuge Size (km^2)	2001	Polygon	United States	(USFWS 2001)
Landscape Road Density (m/ha)	2000	Polygon	United States	(U.S. Census Bureau 2001)
Refuge Elevation Range (m)	Static	1 km^2	Global	(USGS 1999)
Latitudinal Range	2001	Polygon	United States	(USFWS 2001)

Table 2. 3. Summary Statistics for Refuge Climate Change. Statistics calculated for 527 refuges using the spatial average for each refuge. Sea level rise represents the distance to coast as a function of elevation and horizontal distance.

Climate Variable	Mean (SE)	Median	Range
PRISM Change in Mean Annual Daily Minimum Temperature (°C)	0.79 (0.02)	0.77	-0.61 – 2.19
PRISM Change in Mean Annual Daily Maximum Temperature (°C)	0.29 (0.02)	0.28	-0.79 – 2.21
GHCN-ERSST Temperature Trend (°C/decade)	0.21 (0.005)	0.21	0.01 – 0.69
PRISM Annual Precipitation Change (mm)	49.2 (2.22)	44.3	-106.1 – 280.0
Sea Level Rise (km)	460.7 (20.97)	270.8	0.02 – 1603.7

Table 2. 4. Summary Statistics for Refuge Resilience. Statistics calculated for 527 refuges using the spatial average for each refuge.

Resilience Variable	Mean (SE)	Median	Range
Refuge Size (km^2)	866.9 (282.4)	35.3	0.004 – 106672.5
Landscape Road Density (m/ha)	13.9 (0.44)	12.2	0 – 78.1
Refuge Elevation Range (m)	115.8 (14.05)	22.0	0 – 2559

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Chapter 3 Perceptions of How to Manage Climate Change Impacts in the National Wildlife Refuge System

I have read many definitions of what is conservationist, and written not a few myself, but I suspect the best one is written not with a pen, but with an axe. It is a matter of what a man thinks about while chopping, or while deciding what to chop. A conservationist is one who is humbly aware that with each stroke he is writing his signature on the face of his land.
Aldo Leopold, A Sand County Almanac, 1949

3.1 INTRODUCTION

The National Wildlife Refuge System (NWRS) is managed with the overarching mission to "*administer a national network of lands and waters for the conservation, management, and where appropriate, restoration of the fish, wildlife, and plant resources and their habitats within the United States for the benefit of present and future generations of Americans*" (Public Law 105-57). The NWRS is of global significance because of the size and conservation value of the land network. The NWRS includes approximately 38 million hectares in over 540 refuges distributed across all 50 states. NWRS lands include highly productive sites at low elevations that are not represented by other federal land-holding agencies within the national protected areas network (Scott et al. 2004). NWRS lands provide habitat for over 1,300 animal species, including approximately 186 threatened or endangered animals (America's National Wildlife Refuges Fact Sheet, Czech 2005).

Climate change impacts provide new management challenges for NWRS employees working to maintain the biological integrity, diversity and environmental health of refuge lands. The mean global surface temperature has increased 0.74°C since the early 1900s and the rate of increase has nearly doubled over the last 50 years (Solomon et al. 2007). Across taxa, a globally coherent fingerprint of climate change impacts had emerged with species shifting distribution northward and phenological events appearing earlier (Parmesan and Yohe 2003). Species respond to climate change independently due to differences in physiology, life-history, and dispersal ability, creating potential asynchrony with food or habitat (Parmesan 2006). Consequently, novel species assemblages will occur in the future (Root and Schneider 2001). Furthermore, species with limited geographic ranges and limited dispersal ability are more likely to become extinct (Thomas et al. 2004, Parmesan 2006).

Species and ecosystems are also affected by climate change impacts such as sea level rise, changes in snow cover, changes in hydrological regimes, and changes to disturbance regimes (Rosenzweig et al. 2007). Even with stabilized or reduced emissions, future projections of climate change suggest that impacts will continue and are likely to accelerate over the next 100 years because of time lags in climate feedbacks (Solomon et al. 2007).

Since the first refuge was established on Pelican Island over 100 years ago, resources within the NWRS have been managed in a relatively static climate. Indeed, most of the environmental legislation of the 1960s and 1970s were written during the climatically most stable period in the past century. Consequently, wildlife management in general has evolved since the 1930s without consideration of a changing climate. Implicit in restoration ecology and wildlife management is that historical conditions were somehow better or more desirable (Choi 2007). For example, most North American Bird Conservation Initiatives (NABCI) plans assume deviations from historical population estimates, both increases and decreases, are undesirable.

As climate change impacts on fish and wildlife resources become more apparent, managers will have choices (often conflicting) about how to adapt. Managers can do nothing, they can facilitate ecological transitions, or they can resist ecological transitions. Adaptation in a social context is defined as "*the adjustment in natural or human systems in response to actual or expected* *climatic stimuli or their effects which moderates harm or exploits beneficial opportunities*" (Parry et al. 2007: 6). On NWRS lands, adaptation options can be focused on maintaining current ecological conditions by reducing the magnitude of climate change impacts. Alternatively, another option is to focus on management that increases the capacity of the ecosystem to adapt toward likely future conditions. In other words, as the environment changes, managers can use a reactionary strategy that maintains or restores past conditions or an anticipatory strategy that enhances or promotes future ecological states (Easterling III et al. 2004). Resource managers in the NWRS have little guidance on how to adapt to climate change impacts (GAO 2007). However, factors like landscape context, influential policies, and individual conceptualizations of climate change as a management problem may influence decision-making. In this chapter, I tested whether managers will be more likely to choose reactionary strategies when other anthropogenic landscape drivers mask climate change impacts and when influential refuge policies focus on endangered species or natural systems. I also tested whether managers are more likely to choose anticipatory strategies when they are in geographic areas with accelerated warming, when they conceptualize climate change as a natural process, or when they have undergone a planning process that addressed climate change.

In detail, I surveyed Refuge System mangers and biologists to (1) document what climate change impacts and other landscape drivers respondents think are influencing their refuges, (2) understand if climate change is currently included in planning, and (3) explore whether management preferences focus on reactionary or anticipatory adaptation strategies.

3.2 BACKGROUND

3.2.1 NWRS Policy and Legislation in the Context of Climate Change

Currently, the most influential legislation for the NWRS is the National Wildlife Refuge System Improvement Act of 1997 (Refuge Improvement Act; Public Law

105-57) which organized all the individual refuges into a system with the mission of "*conservation, management, and where appropriate, restoration of the fish, wildlife, and plant resources and their habitats*". The Refuge Improvement Act provides a hierarchy of uses for all refuges with conservation first, wildlife-dependent recreation second, and lastly, other uses. The Refuge Improvement Act also requires that refuges write a strategic planning document, the comprehensive conservation plan (CCP), every 15 years that outlines a vision statement for the refuge, management goals, and possible management alternatives. Finally, the Refuge Improvement Act outlines substantive management criteria to provide guidance for NWRS administration. These criteria include compatibility of all refuge activities with conservation; the maintenance of biological integrity, diversity, and environmental health; water right acquisition; ecological monitoring; and conservation stewardship.

Conservation biologists have focused on the substantive criteria of biological integrity, diversity, and environmental health because they require coordinated ecosystem management of NWRS lands (Meretsky et al. 2006). These terms are defined in the 2001 Policy on Maintaining the Biological Integrity, Diversity, and Environmental Health of the National Wildlife Refuge System (BIDEH; RIN 1018 – AG47; see Table 3.1).

Although the Refuge Improvement Act provides a unifying conservation mission for the NWRS, the management mandate of individual refuges continues to be the establishment purposes (Meretsky et al. 2006). Each refuge within the NWRS was established with either an executive order or legislation that includes a purpose for the refuge lands. In 1903, Theodore Roosevelt set this precedent when he established the first refuge, Pelican Island, as a sanctuary for bird populations. Roosevelt began the history of refuge lands being set aside with specific conservation purposes that are crystallized in establishment orders or legislation. This history has lead to a mosaic of refuges with different sizes, acceptable uses, and degrees of federal ownership and control (Fischman 2003).

Establishment purposes range from species protection (e g., inviolate sanctuary for bird populations) to endangered species protection to a focus on the development and management of populations (e.g., waterfowl production, elk management). The original purposes influence the legislation and policy that primarily affects each refuge and therefore promotes reactive adaptation strategies at the expense of anticipatory strategies to adapt to climate change. Many establishment purposes focus on single species or species groups, like bison management, an endangered species, or waterfowl production. Changes in habitat and/or physiological constraints due to climate change may compromise the ability of certain refuges to meet these types of establishment purposes. Local extirpation of populations will logically occur as species distributions shift upward in elevation and northward in latitude. The legislative primacy of establishment purposes will make it difficult for these refuges to not aggressively manage against climate change impacts to maintain these species even if those species are becoming common in other areas outside of the refuge boarder.

Refuge administration is also constrained by other national legislation that cannot be violated to meet refuge purposes. In designated wilderness areas, the 1964 Wilderness Act requires those lands be managed to preserve wilderness character. Refuges with endangered species must adhere to the 1973 Endangered Species Act, which requires specific actions to maintain critical habitat and protect populations. The legislative requirements of the Endangered Species Act may force managers to maintain populations of endangered species in the refuges where they currently occur. If viable habitat for those species shifts with climate change, managers may not be able to translocate endangered species to new areas that fall outside of the historical range of the species (other than as experimental populations that have little protection under current legislation).

3.2.2 "Historic" and "Naturalness" as Conservation Concepts

Within NWRS policies and legislation, historic conditions and naturalness emerge as conservation themes that will be difficult to interpret in a world with accelerated climate change. For NWRS lands, historic conditions are defined as the "*composition, structure, and functioning of ecosystems resulting from natural processes that we believe, based on sound professional judgment, were present prior to substantial human related changes to the landscape*" (BIDEH; RIN 1018 – AG47). The most common reference point for historic conditions in the United States is pre-European settlement (Davis 2000). However, historic conditions will likely not be useful management benchmarks under scenarios of climate change (Millar and Wollfenden 1999). Language in refuge policy has been interpreted to give managers flexibility in meeting the goal of biological integrity when there are limitations in maintaining or restoring historic conditions (Schroeder et al. 2004, Meretsky et al. 2006). However, it is unclear how individual managers will decide whether historical conditions are possible to maintain given climate change impacts. It is also unclear which adaptation options will be acceptable if the historic condition is abandoned. Management for historical conditions could lead to reactionary adaptation strategies that rigidly manage against climate change impacts in order to maintain or restore the historical benchmark.

Naturalness has been defined as "*the way the system would function in the absence of humans*" (Anderson 1991). Naturalness is similar to historic condition, but without explicit reference to past conditions as a benchmark for conservation. Instead human influence is the benchmark, including the selective pressures and possible overexploitation of aboriginal peoples (Anderson 1991). However, naturalness is usually defined in reference to direct human influence (i.e., hunting pressure, local land-use change) within the lands of interest. Climate change, although generally accepted as human caused, operates on individual refuges indirectly. Within current legislation and policies, each refuge in the NWRS may independently define whether climate change impacts are natural ecological processes or anthropogenic in origin. If it is viewed as natural, anticipatory adaptation options should manage toward future conditions. However, if viewed as anthropogenic, all climate change impacts would decrease refuge naturalness and therefore reactionary adaptation options should restore pre-climate change conditions. In addition, without explicit and consistent policy, managers could engage in both reactionary and anticipatory adaptation within the refuge unit, possibly resulting in conflicting outcomes. Furthermore, these management outcomes may be out of synchrony with the surrounding landscape.

Historic conditions or naturalness can be used to validate management practices that match a variety of manager's conservation preferences and, therefore, may not be consistently interpreted. In addition, the concepts of biological integrity, diversity and environmental health are normative concepts that fall under different schools of conservation philosophy that call into question whether people will interpret the system's mission consistently. Diversity and integrity have been grouped within a *compositionalism* paradigm and environmental health is grouped under a *functionalism* paradigm (Callicott et al. 1999). Compositionalists focus on the species that compose the ecosystem and tend to separate humans from nature. Functionalists focus on ecosystem process and tend to include humans in nature.

3.2.3 How Perceptions Affect Policy Interpretation

Agency personnel manage ecosystems under the constraints of legislation and policies, but understanding management decisions can be difficult. Disconnects can occur between legislative intent and interpretation by managers when the concepts in legislation are vague (Howlett and Ramesh 2003). Although biological integrity, diversity, and environmental health are defined (Table 3.1), these concepts are somewhat ambiguous and used heuristically (Gergely et al.

2000). Furthermore, the biological integrity mandate is secondary when it conflicts with the establishment purposes of individual refuges.

Although management preferences are often cast as scientifically based, NWRS managers have been found to have preconceived ideas about preferred management actions prior to rigorous analysis, and analysis was conducted only to justify these preferences when they were questioned by the public (Gergely 2003). In addition, scientific facts and analysis are not free from the individual preferences. Scientific statements are often framed as objective statements when they include the unstated, normative values of the scientist (Rykiel 2001). Furthermore, individuals interpret scientific facts based on their individual beliefs. Therefore, scientific facts take on meanings that can only be understood from the perspective of the belief system or personal narrative in which a fact becomes embedded (Weber and Word 2001). In fact, individuals often resist information that contradicts their belief system (Sabatier and Jenkins-Smith 1999).

The belief systems of individuals, defined as a complex suite of perceptions about value priorities (e.g., the relative importance of integrity versus environmental health), the causes of problems, and best solutions for problems, are important for understanding how policies will be implemented (Sabatier and Jenkins-Smith 1999). Shared belief systems are a stronger predictor of how an individual will behave than the policies that apply to the individual's management context (Sabatier and Jenkins-Smith 1999).

3.2.4 Landscape Context of Refuges

The effects of global climate change are intertwined with other changes driven by human land-use change and development. Refuges are embedded in landscapes with human land-use, and managers may find it difficult to understand whether changes to ecological communities are due to changing climatic drivers or the loss of ecological resilience. Some refuge lands are islands within urbanized landscapes while others occur in relatively intact landscapes.

3.3 METHODS

I distributed a questionnaire (UAF IRB 07-07; Appendix C) via email to refuge managers and biologists within the NWRS. I compiled an email list of 677 NWRS employees of whom 376 were biologists and 301 were managers. Many refuges are grouped into complexes with only one manager for the complex. Not every refuge has a staff biologist. I emailed the questionnaire and an invitation to participate at least three times.

3.3.1 Questionnaire Design

I designed the questionnaire to elicit four general types of information: (1) background information, (2) what climate change impacts were perceived and documented, (3) if and how climate change was included in planning documents, and (4) perceptions about adaptation strategies (see Appendix D for an example questionnaire). I used the background information, information about climate change impacts, and planning document information to provide context and explanatory variables to analyze the perceptions about adaptation strategies. As a pilot test, I had five refuge employees take the questionnaire and used their comments to revise the questions. Background information included questions about the refuge and the individual employee. I collected the refuge name in order to link questionnaire data to information about recent climate change and ecosystem resilience (Chapter 2).

3.3.1.1 *Perceived Climate Change Impacts*

To document climate change impacts that are perceived by refuge staff, I asked respondents to list climate change impacts they have noticed on their refuges and to note where these impacts have been documented. I also asked respondents to rank the importance of five landscape-scale drivers of change (climate change, land-use change, invasive species, over-exploitation of resources, and pollution) in order to understand if climate change is perceived as an important landscape driver on their refuge. Finally, I asked if respondents thought climate change impacts should be managed as a natural process.

3.3.1.2 *Climate Change in Planning Documents*

In order to understand how climate change was incorporated in planning documents, I asked respondents to indicate if climate change was included in their refuge comprehensive conservation plan (CCP) or in other management documents. The CCP planning process includes a scoping phase where refuge issues are identified by staff and the public, a goal development phase where a vision statement and management goals are developed by refuge staff, and an alternative analysis phase where management alternatives are then developed and analyzed. To understand the level of analysis within the CCP, I asked respondents to identify whether climate change was mentioned generally or if climate change was incorporated into the scoping phase, goal development phase, or in the alternative analysis phase.

3.3.1.3 *Anticipatory or Reactionary Adaptation*

To understand perceptions about adaptation strategies, I designed 21 climate change scenarios (Appendix E) related to the conservation themes of historic conditions and naturalness (Figure 3.1 and Table 3.2). Pilot testing indicated that respondents had difficulty answering questions about adaptation without some ecological context. The climate change scenarios provide ecological context with a generalized story about a conservation issue faced by a refuge. I wrote generalized stories for the scenarios because I was interested in the respondent's philosophy about best conservation practices and not in the complexities of a detailed case study. For each scenario, respondents chose the management response that they believed would best support the mission of the NWRS. I designed two possible management responses for each scenario. The first response was reactionary and focused on maintaining or restoring past conditions. The second was anticipatory and focused toward future conditions.

I designed the 21 scenarios around seven questions (Figure 3.1 and Table 3.2) related to the themes of historic conditions and naturalness. I wrote three scenarios for each of the seven questions. In the three scenarios for each question, the climate impact affected a different target. The three targets were a threatened or endangered species, a single species, or an ecosystem (7 questions x 3 targets = 21 scenarios; Table 3.2). The scenarios used language related to the general theme of the question. I distributed the 21 scenarios amongst three questionnaires; each questionnaire had one scenario for each question and included at least two endangered species, two single species, and two ecosystem targets. I stratified respondents by Fish & Wildlife Service regions and randomly assigned survey respondents within each region to one of the three questionnaires. I randomly ordered reactionary and anticipatory responses for each scenario.

3.3.2 Questionnaire Analysis

I analyzed responses individually and by the refuge or complex. For refuges and complexes, I grouped responses for all individuals working at the same refuge or complex. I calculated the frequency of responses for all questions in the questionnaire (Appendix F).

3.3.2.1 *Perceived Climate Change Impacts*

In order to understand if ecological realities influence perceptions of climate change impacts, I linked a resilience rank, temperature change rank and climate change rate rank generated from a GIS analysis of the NWRS (Chapter 2) to each respondent. Each respondent was linked to these rankings based on the refuge or complex they identified in their questionnaire. When respondents identified a complex, I averaged the rankings for the refuges in the complex. I used a Kruskal-Wallis one way analysis of variance to test whether the resilience rank, temperature change rank, and climate change rank differed for respondents who thought climate change was occurring on their refuge, respondents who did not think climate change was occurring, and respondents who did not know. I calculated a Spearman's rho correlation coefficient to test whether there was an association between the resilience, temperature change, and climate change rank orders and how respondents ranked the importance of climate change as a landscape driver as compared to four other landscape drivers (land-use change, invasive species, over-exploitation of resources, and pollution).

3.3.2.2 *Anticipatory or Reactionary Adaptation*

In order to summarize how receptive a respondent was to anticipatory adaptation strategies, I counted the number of scenario questions where the respondent chose the anticipatory option. I omitted 20 respondents who failed to answer one or more of the scenario questions. For each of the remaining 183 respondents, the number of scenario questions where they chose the anticipatory response ranged from 0 to 7. Three questionnaires were administered with different scenario questions, so I used a Kruskal-Wallis one way analysis of variance to test whether the average number of anticipatory responses varied between the three questionnaire types. I used a Mann-Whitney U to test whether managers and biologists were distinct sample populations for testing the following hypotheses about management preferences.

In order to understand if ecological realities influence perceptions of climate change impacts and management preferences, I linked survey data to the GIS derived resilience rank, temperature change rank, and climate change rank. I calculated a Spearman's rho correlation coefficient to test the following hypotheses:

- H1 low ecosystem resilience (high anthropogenic influence) of the landscape will mask climate change impacts and therefore mangers and biologists will prefer reactionary strategies;
- H2 managers and biologists in geographic areas currently experiencing climate change impacts will be more likely to prefer anticipatory strategies.

I expected the number of anticipatory responses to be positively correlated with the resilience rank, the temperature change rank and the climate change rank.

I also tested 3 hypotheses to understand how policy and the interpretation of policy influenced management preferences about climate change:

- H3 managers and biologists with refuge purposes that are focused on endangered species or natural systems will prefer reactionary strategies;
- H4 managers and biologists that believe climate change is an anthropogenic process will prefer reactionary strategies;
- H5 refuges with management documents addressing climate change will be more likely to prefer anticipatory strategies.

For these hypotheses, I used a Kruskal-Wallis one-way analysis of variance to test for differences in the number of anticipatory responses between groups. I then used *post hoc* Mann-Whiteney U tests to understand which groups differed.

3.4 Results

I distributed the questionnaire to 376 biologists and 301 managers in the NWRS. From the 677 possible respondents, I received 219 returned questionnaires for an average return rate of 32%. Wetland Management Districts and Private Lands Offices employed 16 respondents. I excluded these 16 respondents. The remaining 203 respondents (97 biologists, 104 managers, and 2 with unknown job titles) represented 226 refuges (Figure 3.2). Each region had a respondent from 45 to 50% of their refuges, except in Region 6 (24% refuges represented) and Region 7 (88% refuges represented). Refuge complexes, defined as refuges grouped to share staff and management, employ many respondents and many employees indicated that they represent more than one refuge. I grouped these refuges based on where respondents identified their places of employment. When grouped, respondents represented 101 individual refuges and 48 complexes. Complexes contained an average of 2.9 refuges (*SD* = 1.4; range = 2 – 8).

3.4.1 Perceived Climate Change Impacts

Of the 203 respondents, 76% believe climatic changes have already impacted resources on their refuges (Appendix F, Table F-16). When respondents from the same refuge or complex were grouped, 79% of the refuges or complexes have at least one respondent who believes climate change impacts have occurred. Changes in weather patterns, hydrology, and phenology were the most commonly perceived impacts (Table 3.3). Respondents who believed climate change impacts were occurring, respondents who did not believe impacts were occurring, and respondents who did not know if impacts were occurring did not statistically differ in terms of their refuge's resilience rank (X_2^2 = 2.303, P = 0.316) or temperature change rank (X_2^2 = 3.433, P = 0.180). However these groups did differ in terms of their refuge's climate change rank (X_2^2 = 8.510, P = 0.014). The mean climate change rank was higher for the group of respondents who believed climate change impacts had occurred than for the other two groups.

Climate change impacts have not been documented on 44% of refuges (Appendix F, Table F-19). However, 30% of refuges have documented climate impacts in unpublished refuge reports, and 17% of refuges have documented climate change impacts in the scientific literature.

When respondents ranked five general drivers of landscape change in order of importance to their refuges, landscape change was ranked as the most important by the most respondents (Table 3.4). Climate change was ranked as the most important driver by 13% of respondents. The importance rank for climate change was positively associated with the refuge's resilience rank (r_s = -

0.403, $P < 0.001$) and negatively associated with temperature change rank (r_s = -0.279, $P < 0.001$), and climate change rank (r_s = -0.236, P = 0.001). Respondents from refuges with higher ecosystem resilience and faster rates of temperature change and climate change tended to rank climate change as more important than other landscape drivers.

3.4.2 Climate Change in Planning Documents

Comprehensive Conservation Plans (CCPs) had been completed by 52% of refuges and complexes and 38% were engaging in the CCP process at the time of the questionnaire (Appendix F, Table F-8). Of the 104 refuges or complexes that had completed their CCP, 46% mentioned climate change at least generally. However, fewer included climate change as a scoping issue, in refuge goals, or to develop a management alternative (Table 3.5).

Fewer refuges and complexes (only 13%) included climate change in other management plans (Appendix F, Table F-13). Climate change has been included in fire management plans, habitat management plans, biological program reviews and monitoring and inventory plans. All of these plans mentioned climate change generally, and 61% of refuges with climate change in a management plan had formulated a management action in response to climatic changes.

3.4.3 Anticipatory or Reactionary Adaptation

When the ecosystem, species, and endangered species target scenarios were grouped, 60-70% of respondents choose the anticipatory strategy; they focused on future conditions for adapting to climate change for the questions related to range expansion (question 1), the reference point for restoration (question 3), localized extirpation (question 4), and increased extinction risk (question 5) (Figure 3.3). Across targets, 81% of respondents chose the anticipatory strategy for the scenarios related to translocation (question 2). However, only 39% of respondents chose the anticipatory strategy for the scenarios related to natural disturbance regimes (question 7). For natural diversity (question 6), the anticipatory strategy of allowing both colonization and extinction was chosen by only 29% of respondents while 66% of respondents preferred a blended strategy that allowed colonization but not extinction.

When the seven questions were grouped, 56-61% of respondents preferred the anticipatory strategy for ecosystem, species, and endangered species targets (Figure 3.4). The percentage of respondents who chose the anticipatory strategy was similar across targets for the translocation (question 2, range 77-84%), the restoration reference point (question 3, range 59-64%), local extirpation (question 4, range 58-68%), natural diversity (question 6, range 25-32%), and natural disturbance regimes (question 7, range 36-44%) scenarios (Appendix F, Table F-24). The response rate differed across the three targets for range expansion (question 1) and the extinction risk (question 5) scenarios. Fewer respondents chose the anticipatory strategy for the range expansion scenario when the target was an ecosystem (49%) than when the target was a single species (74%) or an endangered species (80%). Fewer respondents chose the anticipatory strategy for the increased extinction risk scenario when the target was an endangered species (57%) than when the target was an ecosystem (72%) or single species (89%).

The average number of anticipatory strategies that respondents chose did not differ among the three surveys with different scenarios ($X_2^2 = 1.074$, $P = 0.585$). Biologists and managers did not differ in the average number of anticipatory strategies chosen ($Z = -0.317$, $P = 0.751$).

3.4.3.1 *Hypothesis 1 and Hypothesis 2*

The average number of scenario questions for which a respondent chose an anticipatory strategy was not correlated with their refuge's resilience rank. Therefore, low resilience did not mask climate effects enough to influence managers to choose reactionary strategies (Table 3.6). The number of anticipatory strategies chosen was also not correlated with temperature change rank (r_s = 0.050, P = 0.506) or climate change rank. Managers in areas with accelerated climate change were not more likely to choose anticipatory strategies (Table 3.6)

3.4.3.2 *Hypothesis 3*

Respondents from refuges with different establishment purposes did not differ in the average number of scenario questions for which they chose the anticipatory strategy. Most notably, respondents with an endangered species purpose did not differ from respondents with a natural diversity purpose (Z = -1.095, P = 0.273) or resource development purpose (Z = -0.29, p = 0.977). Therefore, managers operating under policies influenced by endangered species and natural diversity establishment purposes were not more likely to choose reactionary strategies (Table 3.6).

3.4.3.3 *Hypothesis 4*

The average number of scenario questions for which a respondent chose an anticipatory strategy differed between groups of respondents who categorize climate change as a natural process, respondents who categorize it as an anthropogenic process, and respondents who thought categorizing climate change was not relevant for management. Respondents who categorized climate change as a anthropogenic process were more likely to chose reactionary strategies (Table 3.6) than respondents who categorized climate change as a natural process (Z = -2.20, P = 0.03) or thought categorization was not relevant for management (Z = -2.68, P = 0.01).

3.4.3.4 *Hypothesis 5*

After including climate change in a planning process, respondents did not differ in the number of anticipatory strategies chosen. Respondents whose refuges included climate change in the CCP did not differ from respondents whose refuges did not include climate change in the CCP. Respondents whose refuges had management plans that included climate change did not differ from respondents whose refuges did not include climate change in any management plans ($Z = -1.436$, $P = 0.151$). Therefore, including climate change in a planning process did not influence the likelihood that managers and biologists would chose anticipatory strategies (Table 3.6).

3.5 DISCUSSION

Within the last 20 years, climate change has emerged as a new problem that challenges traditional conservation strategies (Peters and Darling 1985, Halpin 1997, Hannah et al. 2002). Traditionally, biologists largely considered underlying variables like climate to be relatively stable and that, when disturbed, ecological systems would move back toward equilibrium conditions. Therefore, the baseline conditions of undisturbed systems served as relevant benchmarks for restoration (Arcese and Sinclair 1997, Davis 2000). In addition, conservation reserves were designed to protect habitats within their boundaries in perpetuity. With climate change and other anthropogenic stressors, biologists have evidence that ecological systems operate as complex adaptive systems that have the potential to reorganize as conditions change (Scheffer et al. 2001). Therefore, concepts like the historic or natural conditions of an ecosystem may not be relevant benchmarks for all conservation efforts (Millar and Wollfenden 1999).

Although traditional benchmarks of conservation success are now questionable, managers need to respond to the negative effects caused by climate change impacts to protect biodiversity. Within the scientific literature, many adaptation approaches have been identified (Parry et al. 2007, Scott et al. 2008, Heller and Zavaleta 2009). Adaptation approaches range from risk-averse to risk-tolerant strategies and strategy choice may largely depend on an individual manager's tolerance for risk (Heller and Zavaleta 2009). Risk-tolerant strategies are uncertain and anticipatory because these strategies depend on expectations of future conditions. Risk-averse strategies generally increase landscape resilience to allow systems to adapt without human intervention or restore known conditions.

Adaptation strategies can also be categorized as being reactionary or anticipatory (Easterling III et al. 2004). Reactionary strategies are focused on managing toward past conditions, while anticipatory strategies toward future conditions. Reactionary strategies may seem risk-averse because they rely on known conditions, but maintaining ecological conditions that become mismatched with changing climatic conditions will require intensive management with an uncertain prospect of success over the long-term. Anticipatory strategies can be either risk-averse or risk-tolerant. Anticipatory strategies are-risk averse when aimed at using general conservation principles to increase the capacity of ecosystem to adapt without intervention, such as, increasing the size and connectivity of protected lands. Conversely, anticipatory strategies are risk-tolerant when focused on actively transforming ecosystems based on future projections of change. In my analysis, most factors did not influence the likelihood that a manager or biologist would choose anticipatory or reactionary strategies for the climate change scenarios posed in the questionnaire. Perhaps, individual tolerance for risk would be a better indicator of decision-making.

In addition to each manager's individual tolerance toward risk, NWRS policy may influence decisions. Current NWRS polices invoke both natural and historic conditions as benchmarks for measuring ecological integrity, diversity and environmental health. However, individual managers have the authority to decide that historic conditions are not possible to maintain and can pursue other ecological conditions in these situations (Schroeder et al. 2004). Therefore, within the NWRS, individuals with strong tendencies toward risk-averse or risk-tolerant strategies or individuals who believe philosophically in historic conditions will have the ability to manage their refuges according to those beliefs. Indeed, I did not find evidence that refuge purpose, which filters the relevant policy for each refuge, influenced the likelihood that managers or biologists chose reactionary adaptation options.

My analysis indicated that, although climate change has not been included comprehensively in planning, managers and biologists were attuned to climatic changes in their refuges. In addition, ecological realities drove how respondents prioritized climate change as a refuge issue. However, in written comments historic conditions, perceptions about the probability of success, and conceptions of natural systems all influenced how respondents generally believed the NWRS should adapt to climate change.

Written comments indicated that many respondents preferred historic conditions as an ideal ecological condition. However, comments also indicated that most respondents believed it impractical and costly to manage for historic conditions given global climate change. The following quote was representative of the preference toward historic conditions.

> *"I am torn between the ideal and what I feel is practical/doable. ... I think that we cannot hold back the sea level, so we must manage in those cases to adapt. I am less likely to "give in" when I feel there is some hope of managing for the current status"*

When maintaining past conditions was viewed as costly, the majority of respondents who commented preferred adaptation strategies that focused on the natural adaptation of ecosystems. With these adaptation strategies, people seemed to merge change and naturalness. Therefore, respondents preferred options where ecosystems and species respond and humans do not engineer future ecological conditions. For example, this comment explicitly referred to management actions that facilitate natural adaptation.

> *"The refuge system must become more pro-active in acquiring lands, conservation easements or cooperative agreements that will allow species to respond to climate change."*

Another respondent conceptualized the choice as a dichotomous decision between allowing ecosystems to adapt naturally and maintaining past conditions:

> *"I am comfortable in different refuges ending up at different points of the "let nature take its course" v maximum effort to maintain historic conditions."*

Although less prevalent, some respondents' comments did explicitly refer to human choice when considering future ecological condition. In these comments, respondents placed emphasis on enhancing habitat, but using approaches that result in self-sustaining ecosystems. For example, one respondent commented:

> *"The focus of the Fish and Wildlife Service needs to be realigned in an effort to protect and manage habitat that will sustain itself without the massive inputs of energy and money. Currently many of the smaller refuges are forced to invest large sums of time and money to manage habitats for objectives that are not naturally realistic…. I am not philosophically tied to the past and do not see how spending the time and money required to maintain static systems is productive, when we could protect and enhance much more if we were prepared to deal with the dynamic nature of our world."*

Although many respondents believed climate change was beyond the capacity of the NWRS to stop and therefore preferred ecosystems to adapt naturally, reactionary strategies designed to restore historic conditions were not completely rejected. In the questionnaire analysis, respondents who defined climate change as anthropogenic were more likely to choose reactionary adaptation approaches than respondents who defined climate change as natural. However, people's beliefs about the root cause of the problem, whether anthropogenic emissions ultimately cause climate change, were not the only factor driving how to categorize climate change for management. In the comments, I found that the global nature of climate change and the lack of local control for the problem also influenced how people chose to conceptualize climate change. The following comment represented the attitude that, although climate change was driven by anthropogenic inputs, climate change should be treated as natural for wildlife management.

> *"Although I believe the current rate of global warming to be anthropogenic, I think that the inevitable changes that will occur over the next 50 years should be treated as "natural" adjustments that we should not attempt to mitigate in place. This will end up being such a costly undertaking that it will not be feasible. ... Refuges will become zoos if we attempt to maintain existing wildlife populations and habitats given the expected changes from global warming."*

In the comments, many respondents noted that their preference between anticipatory and reactionary strategies depended on both spatial and temporal context. Many comments argued that conditions at larger, regional scales affected their adaptation decisions. In addition, one respondent commented that these strategies were not mutually exclusive. Mangers could apply both strategies in different areas within an individual refuge and then compare them in order to gain additional knowledge:

> *"In many cases there you may opt to utilize a variety of options to address the problems: one solution in one part of the refuge and another in a separate area. And these solutions have to be dynamic and may change as conditions change. Adaptive management techniques will be critical to our success"*

Similar to spatial scale, temporal context was also evoked in the comments as important because, although climatic changes have been documented, many changes are forecasted to occur in the future. Forecasts are uncertain because future conditions are unknown, and our knowledge about how ecological, physical and social systems interact is imperfect. Uncertainty increases as the projection time increases. Therefore, planning for the 100-year timeframe often used in climate projections was more uncertain than planning for the 15-year timeframe of a CCP. When long-term uncertainty was high, many respondents believed NWRS policy should use precautionary measures to ensure biodiversity was not lost. Over the short-term and as a stop-gap strategies, many respondents commented that precautionary measures were appropriate even if those measures were costly, reactionary, and likely to fail over long-time scales. However, respondents believed that long-term strategies needed to be congruent with ecological conditions. The following two comments, by different respondents, were representative of other comments that addressed timescale.

> *"I view many of the scenarios you presented as short term vs. long term. I think in the short term we may have to use some of each approach through use of adaptive management techniques and monitoring. In other*

> *words don't give up too quick, maintain options and see what we as a society can do to slow or change our impacts to the environment."*

> *"In some cases it might be more important to intervene, at least in the short term until we know more."*

In these examples, respondents pointed to uncertainty due explicitly to unknown global mitigation of climatic changes and to uncertainty due to more general knowledge gaps.

Although not adequately addressed in the survey design, respondents do seem less likely to be risk-averse when climatic change affected an ecological process. When answering scenario questions, respondents were more likely to choose reactionary strategies when fire regimes and insect outbreaks were shifting. Respondents seemed more risk-tolerant of changes to species distributions and populations sizes. Many respondents explained that species compositions have changed in the past. For example, one respondent commented,

> *"To my way of thinking, global climate change is too long term for temporary fixes - and there have been changes to flora and fauna since the beginning (whenever that was). To try to preserve the status quo is a loser proposition. I hate to think of extinction of a species (or multitudes of species) but we don't live in a static environment, and short term fixes are for short term problems."*

However, when extinction was imminent, respondents were less likely to be risk-tolerant. For example, in the comments, a respondent noted:

> *"My general attitude is not to fight the climate change, unless it involves saving an endangered species. Some species may be able to shift and occupy newly created habitats, while others are going to take a hit."*

Although respondents were willing to discuss how to adapt to climate change impacts, many contextualized climate change as a larger, societal problem. Respondents acknowledged failures to protect plants, animals, and their habitats from anthropogenic stressors, like urbanization and other land-use change, that are driven by larger, market dynamics. For example, one respondent commented about the need to address human interactions to ecosystems.

> *"As wildlifers, we often talk about managing populations of plants and animals, but as a society, we should be talking about how to manage our human population."*

3.5.1 Conclusion

Climate change provides an opportunity for the NWRS to better articulate how wildlife experts believe humans should be interacting with ecosystems. To this end, a strategic, national adaptation plan will need to define the overall management priorities for the NWRS, and provide a context in which individual refuges can contribute to meeting national priorities. Given the NWRS focus on biodiversity and the likelihood of climate change increasing extinction risk, I argue that the main priority of the NWRS should be to minimize species extinction. To minimize species extinction in a rapidly changing climate, refuge management needs spatial coordination in order to link refugia and transitioning ecosystems. Refuge management also needs to be temporally coordinated to understand when to shift from reactionary to anticipatory actions for a given refuge.

The problem of climate change has challenged many implicit assumptions in wildlife biology, such as historic and natural condition as a valid management goal. These implicit assumptions are important components of the belief systems of wildlife professionals. Educational in-reach must openly acknowledge belief systems for the NWRS to implement a coordinated, national adaptation strategy. In addition, in-reach activities will need to engage managers and biologists in a mutual learning process that will be useful to both further refine NWRS priorities and to build consensus for a national adaptation plan.

Several topics emerge from my analysis that could be an important starting point for the engagement of managers and biologists. As an agency, the NWRS needs to provide a rationale for how climate change should be conceptualized for wildlife management. Currently, managers and biologists are independently deciding if climate change is natural or anthropogenic for wildlife management, and this conceptualization becomes important for deciding whether reactionary or anticipatory adaptation approaches are more appropriate. Additionally, the concepts of historic condition and naturalness could also be useful starting points for engaging biologists and managers. Although many biologists and managers understand that the historic condition may not be possible to maintain, historic condition is still considered the best outcome. My analysis also indicates that managers and biologists prefer that ecosystems and species adapt naturally. In a rapidly changing climate, natural adaptation may not be feasible without large-scale extinction. Nonetheless, many biologists and managers are uncomfortable with the alternative of manipulating ecosystems and species assemblages toward future conditions. There is clearly a need for agency-wide dialogue about how best to interpret the mission of the NWRS.

<u>Historic Conditions</u>

1. Should species expanding their historic range be treated as invasive?
2. Is it acceptable to translocate species outside of their historic range?
3. What temporal reference point should be used for restoration?

<u>Naturalness</u>

4. Is extirpation of a species/habitat from a local geographic area due to climate change natural when it exists elsewhere?
5. Is extinction of a species/habitat due to climate change natural?
6. What should be considered natural diversity given climate change?
7. What should be considered natural disturbance regimes given climate change?

Figure 3. 1. Questions Used to Design Scenarios. The 21 climate change scenarios in the questionnaires were designed around these seven questions related to the themes of historic conditions and naturalness. Scenarios for each question were written with three different management targets: (1) an endangered species, (2) a single species, and (3) an ecosystem.

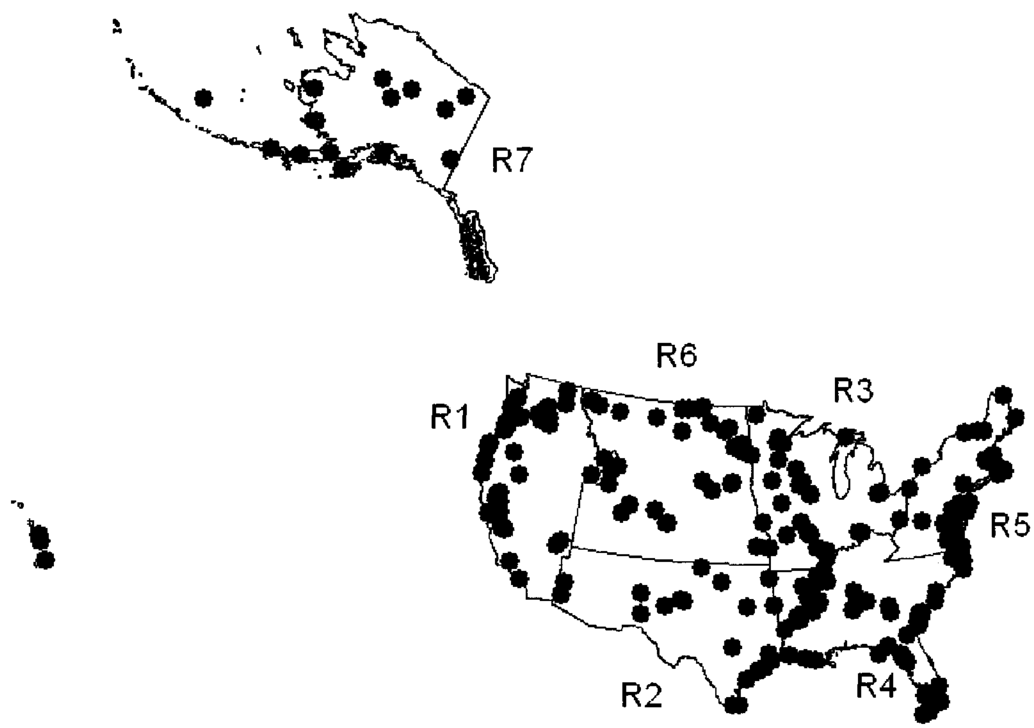

Figure 3. 2. Refuges with Questionnaire Respondents. Refuges with at least one respondent to the questionnaire represented. Red points are located at the center of the refuge. Regions are labeled.

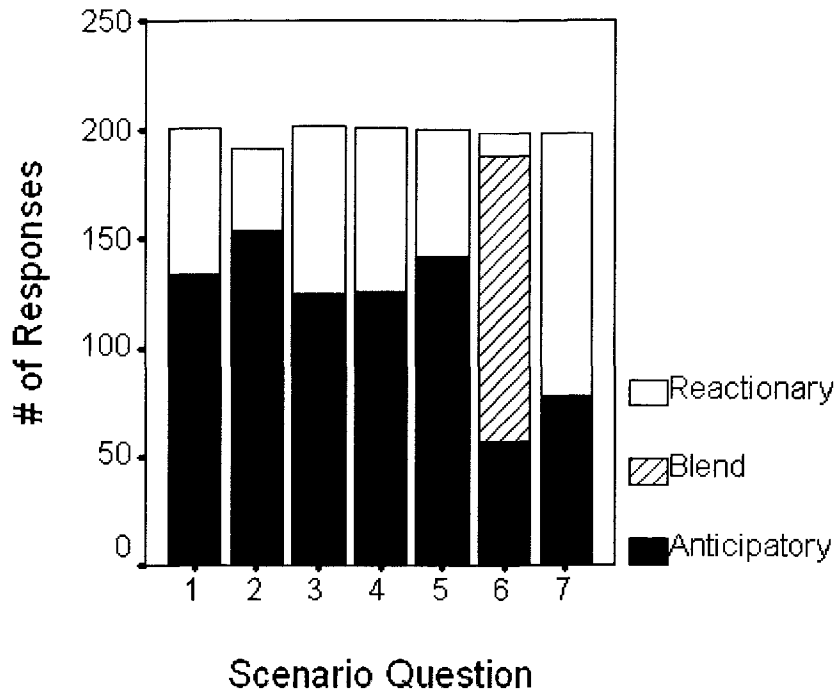

Figure 3. 3. Management Response by Scenario Question. Number of anticipatory and reactionary responses per cllmate change question.

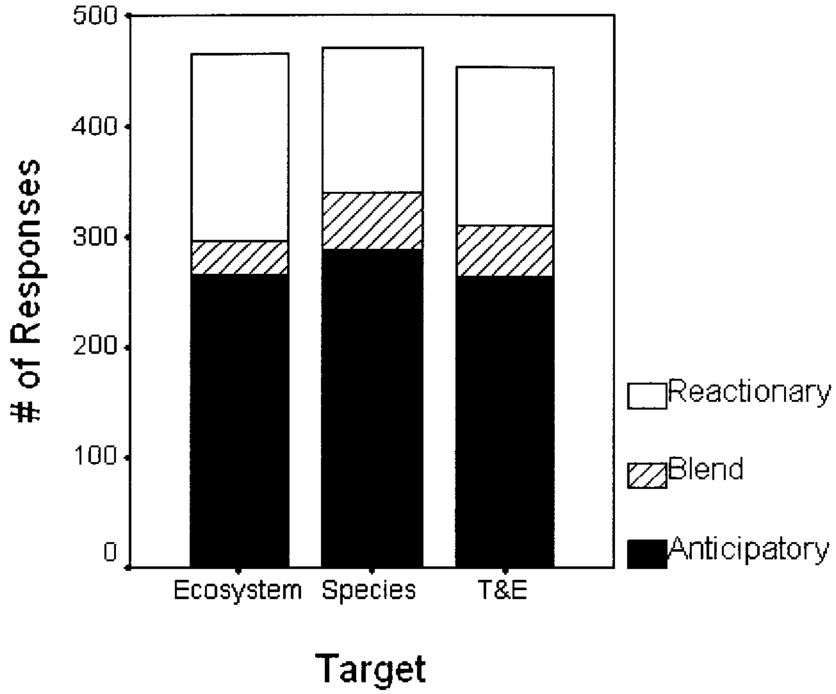

Figure 3. 4. Management Response by Scenario Target. Number of anticipatory and reactionary responses grouped by target (ecosystem, species, or threatened and endangered species).

Table 3. 1. Refuge Policy Definitions. Definitions of major concepts from the 2001 Policy on Maintaining the Biological Integrity, Diversity, and Environmental Health of the National Wildlife Refuge System.

Concept	Definition
Biological integrity	"biotic composition, structure, and functioning at genetic, organism, and community levels comparable with historic conditions, including the natural biological processes that shape genomes, organisms, and communities"
Diversity	"the variety of life and its processes, including the variety of all living organisms, the genetic differences among them, and the communities and ecosystems in which they occur"
Environmental Health	"composition, structure, and functioning of soil, water, air, and other abiotic features comparable with historic conditions, including the natural abiotic processes that shape the environment"

Table 3. 2. Scenario Summary. Scenarios were designed around seven questions (Figure 3.1). Respondents chose between a reactionary response and an anticipatory response. A summary of the anticipatory response and a synopsis of each scenario are provided. For each question, one scenario each was written for an ecosystem, a single species, and an endangered species.

Question	Anticipatory Response	Ecosystem	Single Species	Threatened & Endangered Species
1	Do not treat species expanding their historic ranges as invasive	Mountain pine beetle expanding into Eastern ecosystems	Red fox expanding historic range and competing with Arctic fox	Barred owls expanding historic range and competing with northern spotted owl habitat
2	Translocation outside of historic range is acceptable	Island with unique habitats lost to sea level rise	Desert bighorn sheep habitat shifting	Hawaiian monk seal habitat shifting due to sea level rise
3	Use likely future conditions as the restoration reference point	Reduction in the amount of coastal marshland habitat	Reduction of Canvasback duck population due to habitat loss	Reduction of Hawaiian monk seal population due to habitat loss
4	Local extirpation is natural	Extirpation of alpine patches due to treeline rise	Extirpation of Arctic fox from parts of historic range due to competitive exclusion	Extirpation of historical loggerhead sea turtle breeding populations due to seal level rise
5	Increased extinction risk is natural	Extinction of an island with unique habitats due to sea level rise	Increased extinction risk of Desert bighorn sheep due to reduced forage	Increased extinction risk to Hawaiian monk seals due to loss of beach habitat and pup mortality
6	Colonization and extirpation are both natural processes.	General biome shift	General colonization and extirpation due to shifting distributions	General colonization and extirpation due to shifting distributions
7	Changed disturbance regime is natural.	Increased fire frequency reducing old-growth habitat	Increased fire frequency reducing brown creeper breeding habitat	Increased fire frequency reducing spotted owl habitat

Table 3. 3. Frequency of Various Climate Change Impacts on Refuges. Frequency of individual respondents that believe a particular climate change impact is affecting their refuge. Only respondents that believe climate change has impacted their refuge are included. Respondents from the same refuge or complex are grouped to estimate the frequency of refuges and complexes with at least one respondent who believes the impact is occurring.

Impact	**Individual Respondents n=155**	**Refuge & Complex n=118**
Changes to local weather patterns including extreme weather events	76%	80%
Hydrological change including changes in water volume and timing of hydrological events	72%	72%
Changes to phenology; changes in timing of flowering, breeding, or migration	70%	75%
Increases in exotic, invasive, or injurious species	53%	57%
Shifts in species distributions	49%	53%
Wetland drying	35%	33%
Changes in frequency or duration of disturbances like fire	28%	27%
Habitat changes like rising treeline or the decline of historically dominant tree species	26%	25%
Changing demographics of species of concern	24%	28%
Saltwater inundations or intrusion (sea level rise)	23%	21%
Changes in erosion rates	21%	20%
Other(s)	12%	14%
Desertification	2%	3%

Table 3. 4. Ranked Importance of Ecosystem Change Drivers. Respondents (n=203) ranked five general drivers of ecosystem change from the most important (1) to least important (5).

Driver of Change	1	2	3	4	5
Landscape change and land-use conversion including, but not limited to urbanization	46%	25%	11%	9%	9%
Increasing influence of invasive, exotic, or injurious species	32%	32%	16%	11%	9%
Climate change	13%	12%	27%	22%	25%
Over-exploitation of resources including hunting, recreation demands, or extractive resource use	7%	14%	19%	22%	36%
Pollution including contaminants	2%	15%	28%	35%	20%

Table 3. 5. Climate Change Inclusion in Comprehensive Conservation Plans. Percentage of refuges or complexes that included climate change In a Comprehensive Conservation Plan (CCP) phase.

CCP Phase	Climate Change Included	Climate Change Not Included	Phase Not Complete
Scoping	19%	61%	9%
Goal Development	8%	76%	16%
Alternative Development	4%	76%	20%

Table 3. 6. Hypotheses Summary. Summary results for hypotheses testing the factors that influence managers and biologists to choose reactionary or anticipatory adaptation strategies.

Hypotheses	Result	Test Statistic	P value
H1 refuges with low resilience prefer reactionary strategies	Rejected	$r_s = 0.051$	0.502
H2 refuges experiencing climate change impacts prefer anticipatory strategies	Rejected	$r_s = 0.120$	0.112
H3 respondents with refuge purposes focused on endangered species or natural systems will prefer reactionary strategies	Rejected	$X_4^2 = 8.50$	0.075
H4 respondents that believe climate change is an anthropogenic process will prefer reactionary strategies	Supported	$X_2^2 = 9.378$	0.010
H5 refuges with management documents that address climate change will prefer anticipatory strategies	Rejected	$Z = -1.082$	0.279

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Chapter 4 Predicted Species Distribution Maps as a Management Tool for Understanding Climate Change

It is fortunate, perhaps, that no matter how intently one studies the hundred little dramas of the woods and meadows, one can never learn all the salient facts about any one of them.
Aldo Leopold, A Sand County Almanac, 1949

4.1 INTRODUCTION

Documented range shifts for species have been linked to climate change (Parmesan 2006). Range shifts, as species move both into and out of geographic areas, are important ecologically because changes in species composition have the potential to affect ecosystem function (Root and Schneider 2001). In addition, threatened and endangered species may require habitat reserves that will maintain populations under future climatic conditions. Therefore, conservation planning requires an understanding of how species composition will change spatially as the climate changes. However, basic information about how plants and animals are distributed across the landscape is often unavailable (Guisan and Thuiller 2005). The NWRS, the only U.S. land-holding agency with a mission to conserve biological diversity, still lacks basic species inventories and therefore has little information about the spatial distributions of species (Meretsky et al. 2006, Scott et al. 2008).

Predictive species distribution models provide a powerful solution for the lack of information about how species are currently distributed across the landscape. Data-mining algorithms, like Random Forests, can produce accurate species distribution models even when there is little *a priori* knowledge available regarding the factors driving the distribution (Hochachka et al. 2007). With climate variables as predictors, species distribution models have also been used to forecast range shifts under climate change scenarios. For example, at the regional scale, range shift forecasts have been projected for Mexican fauna (Peterson et al. 2002) and flora in the Eastern United States (Iverson et al. 2004). When applied to future climate conditions, bioclimatic species distribution models often predict species turnover. In the Western hemisphere, at least 10% of vertebrate species are projected to be lost locally under scenarios based on low greenhouse gas emissions, with regions like the arctic tundra experiencing over 90% turnover by 2100 (Lawler et al. 2009).

Bioclimatic species distribution models do have limitations for forecasting future ranges. Species distribution models are based on the assumption of equilibrium conditions and the concept of a stable, ecological niche (Guisan and Thuiller 2005). Climate change will result in transitional ecological conditions not captured in the species distribution model. Species distributions are generally limited by physiological limits, dispersal ability, the legacy of historic disturbances, and the spatial distribution of current resources (Guisan and Thuiller 2005). Bioclimatic species distribution models capture physiological conditions and proxy information about the spatial distribution of resources. When forecasting future conditions, species distribution models often assume unlimited dispersal, and biotic interactions are not captured (Pearson and Dawson 2003). In addition, species entering new areas may not occupy the identical niche and may occur in novel habitats. For example, Australia's invasive cane toad (*Chaunus [Bufo] marinus*) has expanded beyond the range of the toad's predicted bioclimatic envelope (Urban et al. 2007). Finally, uncertainty associated with the methodologies employed and scale of the species distribution model can add to the uncertainty already associated with future projections (Thuiller 2004).

Although species distribution models have limitations, other tools are not readily available for assessing climate change impacts for a wide range of species (Guisan and Thuiller 2005). Models of current distributions, along with accurate error assessments, provide a useful benchmark for identifying future change (Magness et al. 2008). NWRS managers need to project probable shifts in species and assemblages and then manage lands toward future conditions (Scott et al. 2008).

Providing accurate, spatial distribution information will be useful for the NWRS. Producing this information for Alaskan refuges is a significant challenge because of their size and remoteness. However, this information is critical because Alaskan refuges are experiencing climate change rates that exceed other geographic regions (ACIA 2005). In this chapter, I used the Kenai National Wildlife Refuge (KENWR) as a case study to explore how wildlife management could approach the problem of climate change at an operational scale. To document current ecological conditions, I built bioclimatic species distribution models for Swainson's thrush (*Catharus ustualtus*) and golden-crowned sparrow (*Zonotrichia atricapilla*) using data from the KENWR's monitoring program. I then forecast future range shifts under two climate change scenarios.

4.2 KENAI NATIONAL WILDLIFE REFUGE (KENWR)

The Kenai National Wildlife Refuge (KENWR) encompasses 7722 km^2 on the Kenai Peninsula in south-central Alaska (Figure 4.1). The KENWR location provided an interesting case study for climate change research because the interface between the boreal forest and coastal rainforest ecoregions occurs within the refuge boundary. The location at an eco-region boundary and the broad elevation range of the refuge (sea level to 2000 m) create a diverse array of habitat types (Hulten 1968). West of the Kenai Mountains, refuge lands are boreal lowlands characterized by pothole lakes, extensive peatlands, and forests dominated by black spruce (*Picea mariana*) and white spruce (*Picea glauca*). Aspen (*Populus tremuloides*) and birch (*Betula neoalaskana*) stands are interspersed within the spruce forests. Sitka spruce-dominated (*Picea sitchensis*) stands extend from the coastal rainforest along the southern portions of the Kenai Peninsula. Mountain hemlock (*Tsuga mertensiana*) and sub-alpine shrub habitats turn to lichen-dominated tundra along an elevational gradient in the Kenai Mountains and Caribou Hills. The refuge also includes portions of the Harding Ice Field.

4.2.1 Long-term Ecological Monitoring Program

The KENWR provided an excellent case study for projecting range shifts because data were available from the refuge's Long-term Ecological Monitoring Program (LTEMP; Morton et al. 2009). LTEMP utilizes a context monitoring approach to document ecological condition and biodiversity. For context monitoring, data are collected to document a broad array of ecosystem components, at multiple scales, without reference to management activities (Holthausen et al. 2005). LTEMP collects information in conjunction with the U.S. Forest Service's Forest Inventory and Analysis program (FIA) on a 4.8-km resolution systematic sampling grid. Ecotypes are sampled in direct proportion to their prevalence on the landscape. At each sampling location, FIA collects detailed vegetation information but only in forested ecotypes. LTEMP extended the sampling framework to non-forested ecotypes and linked other information about terrestrial flora and fauna to the vegetation plots. In the first three years after the establishment of LTEMP, all plots were visited once to establish a baseline sample for a variety of metrics, including avian diversity. Although many monitoring metrics are possible with the LTEMP dataset, we focus on species distribution models because range size, when compared at multiple time-steps, was identified by Angermeier and Karr (1994) as an appropriate metric for ecosystem change. In addition, distribution maps can also be linked to population estimates (Boyce and McDonald 1999, Yen et al. 2004).

4.3 METHODS

4.3.1 Passerine Occurrence: LTEMP Field Collection Methods

Breeding passerine populations were sampled on 255 LTEMP plots (Figure 4.1) using variable circular plot methodology (Buckland et al. 2001) — 152 in 2004 and 103 in 2006. The LTMEP plot locations are regularly spaced in a 4.8-km systematic grid. Observers accessed the LTEMP plots via helicopter. Observers walked from the helicopter landing site to the point count sampling locations. During each point count, an observer recorded the species and distance from point center of all birds seen and heard within a 10-minute sampling period. At each point, one of two skilled observers conducted the point counts. The two observers sampled plots across the range of habitat conditions. Observers conducted the point counts during the last 3 three weeks of June when weather conditions were clear, with little or no precipitation, and light wind. Bird sampling protocols were approved by the University of Alaska, Fairbanks Institutional Animal Care & Use Committee (IACUC # 07-13).

For model building, I used the occurrence of Swainson's thrush and golden-crowned sparrow. I defined occurrence as a bird being located within 200 m of the point count location within the 10-minute sampling period. I excluded birds observed flying over the sampling area from the analysis. If a species was not encountered within the 12.56 ha (200-m radius) sampling area during the 10-minute sampling period, I assumed the species was absent. However, the probability of detecting a given species within a sampling window differs by species and increases with increasing sampling time (Dawson et al. 1995).

In 2007, the same two observers collected data at 30 validation plots (Figure 4.2). The observers followed LTEMP sampling protocols, but plots were accessed by road, and plots were sampled every week during the 3-week sampling period. The 30 plots were distributed across habitat types.

4.3.2 Climate Layers

4.3.2.1 *Current Climate*

I calculated 58 variables to represent current climate conditions (Table 4.1) using 1-km resolution historic climate data provided by the Scenarios Network for Alaska Planning (SNAP, http://www.snap.uaf). For each year in the historic dataset, SNAP provided monthly average air temperature (°C) and precipitation (mm) layers generated with the Parameter-elevation Regression on Independent Slopes Model (PRISM; www.ocs.orst.edu/prism). The PRISM methodology fits local linear regressions of climate versus elevation, but also includes information about terrain barriers, terrain induced climate transitions, cold air drainage, inversions, and coastal effects (Daly 2006).

Historic data were available from 1901-2002. To summarize current climate in the KENWR for the 2004 and 2006 sampling period, I used the 1998 - 2002 historic data. For each month, I calculated a mean and standard deviation for the 5 years of average monthly air temperatures and precipitation (48 layers). I used the 5-year monthly means for temperature and precipitation to calculate an additional 10 bioclimatic variables (Table 4.1).

4.3.2.2 *Future Climate*

SNAP also provided yearly, future projections of monthly average air temperature and precipitation. In order to provide spatial climate data at a 2-km resolution, SNAP linked PRISM data to five General Circulation Models (GCMs) that perform well in Alaska (http://www.snap.uaf.edu). I used monthly temperature and precipitation outputs based on a compilation of the five GCMs. GCMs are complex global models used by the Intergovernmental Panel on Climate Change (IPCC) to simulate climate systems. GMCs provide forecasts of future climatic conditions based on alternative emission scenarios (Nakicenovic et al. 2000). The IPCC uses scenarios as storylines with alternative emission outputs and driving forces, like demographic development, socio-economic development, and technological change. The scenarios represent a range of possible future conditions. For this analysis, I used outputs from the A2 and B1 emission scenarios because they represent a wide range of future conditions. The A2 storyline describes a world where regions are self-reliant, regional identities are preserved, the global population grows, and technological change is fragmented. The A2 scenario results in higher future emissions. The B1 storyline describes a world where global population peaks then declines, economies shift rapidly toward service and information, clean technologies increase, and resources are used more efficiently. The B1 scenario results in lower future emissions (Nakicenovic et al. 2000).

For the A2 and B1 scenarios, I generated climate data for three time-periods: 2025, 2050, and 2099. For each time-period, I used 5 years of data to calculate 58 variables using the same methodology as was used for the historic data (Table 4.1). The 5-year data periods were 2021-2025, 2050-2054, and 2095-2099.

4.3.3 Model Development with Random Forests

Random Forests, a data-mining algorithm developed by Leo Breiman and Adele Cutler, produces accurate predictions without overfitting (Breiman 2001). Random Forests constructs a classification or regression tree by successively splitting data based on single predictors. Each binary node, or split, forms a branch in a decision tree. However, Random Forests does not grow only one decision tree. Instead, Random Forests utilizes bagging, or “bootstrap aggregation”, a technique that builds a large number of decision trees and averages the output. For bagging, a bootstrap sample (Efron and Tibshirani 1993) of 2/3 of the data set is randomly drawn to build each decision tree. Data not in the bootstrap sample, termed “out-of-bag”, are used to estimate an unbiased error rate. Before each decision tree is constructed, a new bootstrap sample is randomly drawn. Resampling the training data for each tree reduces output error caused by the structure of the data set. In order to decrease bias due to correlation among decision trees, Random Forests also perturbs tree construction by only considering a random subset of all predictors while searching for the best predictor to use at each node.

With the 58 variables representing current climate, I built models for Swainson's thrush and golden-crowned sparrow with Salford System's commercial version of Random Forests. Random Forests has the ability to weight observations based on the proportion of observations in each class. I allowed Random Forests to balance the weights, so species abundance would not influence the predictive ability of the model. Without weighting, classes with more observations would have a greater influence on the model than classes with fewer observations. Users may vary the number of predictors randomly selected for consideration at each node; and classification error may be influenced by this parameter, termed the "mtry" parameter. I ran models with a range of mtry values and chose the value that produced the lowest error rate. For Swainson's thrush and golden-crowned sparrow, an mtry of 1 was selected.

For each species, I built 5000 decision trees. I used the Receiver Operating Characteristic (ROC) to provide a metric of predictive ability that is independent of the classification threshold (Pearce and Ferrier 2000). A ROC value of 0.5 indicates no predictive ability and a value of 1.0 indicated perfect predictive ability (Boyce et al. 2002). I also used the out-of-bag prediction error rates to understand the predictive ability of each model. Random Forest calculated the out-of-bag prediction errors from the 1/3 of the data not selected for the bootstrap sample used to build each decision tree. I also calculated an error matrix for the 30 validation plots. For the 30 validation points, I obtained indices of occurrence by overlaying the points onto the distribution maps (Figure 4.2).

4.3.4 Current and Future Distribution Maps

I generated a 1-km resolution prediction grid across the spatial extent of the refuge and linked the predictor variables (both current and future climate) to the points using Hawth's Analysis Tools (www.spatialecology.com/htools). I used the Swainson's thrush and golden-crowned sparrow model groves, which are the multiple decision trees that generate a plurality vote for output, to score the seven prediction grids. The seven prediction grids represented climate conditions for current conditions and 2025, 2050, and 2099 conditions under the A2 and B1 emission scenarios. I imported the scored points back into GIS and converted the points into a grid with a 1-km^2 pixel size; each pixel value represents an occurrence index for the prediction grid point located at pixel center. Occurrence indices generally ranges from 0–100%. I binned values into 10% intervals for the map display.

4.4 RESULTS

4.4.1 Current Distributions and Model Assessment

Swainson's thrush's current distribution was concentrated in the boreal forest lowlands of the KENWR (Figure 4.2). The ROC value was greater than 0.8 (Table 4.2) indicating a strong model. The predictive ability of the model ranged from 74% for the out-of-bag data to 80% for the validation data (Table 4.2).

The current modeled distribution for golden-crowned sparrow was sub-alpine and lower elevation alpine shrub habitats of the KENWR (Figure 4.2). The ROC value was greater than 0.85 (Table 4.2). The predictive ability of the model ranged from 76% for the out-of-bag data to 86% for the validation data (Table 4.2). However, the predictive ability for occurrences was lower for the validation data than for the out-of-bag data. Two alpine plots in the Mystery Hills and one sub-alpine plot where golden-crow sparrow occurred were misclassified by the model; this error was likely due to the resolution of the climate data not capturing small habitat patches.

4.4.2 Future Distributions

For both the A2 and B1 emission scenarios, the range for Swainson's thrush shifts out of the KENWR boundary (Figures 4.3 and 4.4). Only the lower emission B1 scenario predicts Swainson's thrush will occur in a small pocket within the KENWR boundary in 2025. Both emission scenarios predict Swainson's thrush will not occur in the KENWR in 2050.

Conversely, the range of golden-crowned sparrow expands across the entire KENWR in the A2 and B1 emission scenarios by 2050 (Figures 4.5 and 4.6). Only a small area in the KENWR will not be included in the golden-crowned sparrow distribution under the low emission B1 scenario in 2035.

4.5 DISCUSSION

Global climate change is a pressing, but complex problem that will cause changes to species ranges. Many species will face increased extinction risk if they are unable to respond in pace with climatic changes. Additionally, as species independently respond to a rapidly changing climate, new species assemblages will occur (Root and Schneider 2001). New species assembles will change species interactions and this could also increase extinction risk. The Refuge Improvement Act emphasizes that NWRS lands should be managed as a system of lands to conserve biodiversity (Public Law 105-57). Therefore, the NWRS needs a strategic adaptation plan to minimize extinction in a rapidly changing climate. A strategic adaptation plan requires spatial and temporal coordination to link climate refugia with transitioning areas. However, deciding how, where, and when different biodiversity components should exist biogeographically will be a complex problem for refuge management.

Species distribution modeling provides an approach that is useful for both documenting current conditions and forecasting future conditions. For current conditions, most refuges do not have reliable information about where species occur within refuge boundaries (Meretsky et al. 2006, Scott et al. 2008). Random

Forest quickly produced maps that corresponded with biologist's knowledge of where Swainson's thrush and golden-crowned sparrow occur on the KENWR. For managing biodiversity, managers need information for suites of species with little *a priori* information about the processes that influence their distributions. Algorithmic models have the ability to provide accurate distribution maps for rare species (Magness et al. 2008) and for species whose habitat relationships are not well understood (Hochachka et al. 2007).

Species distribution modeling is also a useful approach for understanding future conditions. In my analysis, both bird species were projected to have significant range shifts within the next century. Although habitat and therefore bird species may not shift as quickly, climatic conditions were projected to shift for both species over the next 15 years. In Alaska, Swainson's thrush distribution generally intersects the boreal forest region (Mack and Yong 2000). The predicted current distribution for Swainson's thrush in the KENWR was also consistent with the distribution of boreal forest habitat. The boreal forest is expected to expand Northward with climate change, but with time lags (Fischlin et al. 2007). Conversely, golden-crowned sparrow was projected to expand across the entire KENWR from the sub-alpine and low elevation alpine shrub habitats where it currently occurs. In other maritime regions of Alaska, golden-crowned-sparrow is currently abundant in low elevation alder (*Alnus*) and willow (*Salix*) patches (Norment et al. 2000).

When projected to climate forecasts, bioclimatic distribution models function best as learning tools and not as predictions of the future. For both Swainson's thrush and golden-crowned sparrow, I was initially surprised by the range shifts under the future climate scenarios. Only after thinking about where each species currently exists in Alaska and throughout their entire range, I was able to provide explanations for the projected future ranges. The models forced me to think about each species at scales larger than the refuge boundary and under conditions that I had not expected. Future projections and the corresponding ideas about possible future conditions need to be treated as hypotheses, but they do give land managers a starting point.

Protecting biodiversity across the NWRS will require planning across multiple scales while anticipating the ecological conditions that can be sustained in various geographic areas as climatic conditions change. In addition, planning processes will need to address the future choices that are possible for local ecologies. In some cases, several new ecotypes could be supported with the new climate regime. In those cases, a public planning process, like the Comprehensive Conservation Plan (CCP), will need to address the rationale (both locally and within the context of the NWRS) behind management actions aimed to transform the ecosystem to new conditions that are compatible with changing climatic conditions. Forecasts of future species distributions can help to bound discussions about the range of ecological conditions that will be congruent with a region's rapidly changing climatic conditions. When multiple species are modeled, the stacked maps can provide information about the species assemblages that could occur in localized areas.

The KENWR, and other Alaskan Refuges are experiencing rapid, climatic change (ACIA 2005). Managers in Alaska have already witnessed habitat change and other landscape changes due to changes in climatic conditions. For example, the KENWR has become drier in the lowlands (Klein et al. 2005), tree-line has risen in the mountains (Dial et al. 2007), and extensive bark beetle infestations with spruce mortality has occurred across the southern refuge (Berg et al. 2006). However, ecological resilience in Alaska is also high. Alaskan refuges are large enough to encompass ecological processes. The KENWR is the smallest refuge and still includes over 8000 km^2. The largest Alaskan refuges, Yukon Flats National Wildlife Refuge and Arctic National Wildlife Refuge, are over 80,000 km^2. Large elevation and latitude ranges occur within refuge borders, so connectivity for landscape movement of wildlife should not be restricted. In addition, industrial landscape features, like roads, are not dense in the surrounding landscape matrix. With high ecological resilience and fate rates of climate change, Alaskan refuges provide the NWRS with an opportunity to study how ecological systems will change. Even with a strategy for natural adaptation, managers will still need to have accurate information about the current spatial distributions of species in order to document future change. Additionally, the mission of the NWRS is to maintain the natural diversity of ecosystems, including arctic mammals whose ranges will likely be extremely constricted under scenarios of climate change. Furthermore, the rapid rate of climate change and dramatic changes to species assemblages may increase extinction risk. When components of biodiversity are threatened, even managers in Alaska may need to promote habitat for species of concern as refugia, corridors, and transitional habitats.

In order to effectively utilize species distribution models for strategic adaptation planning, the NWRS must link monitoring initiatives with an increased modeling capacity. Monitoring efforts should include a spatial sampling frame in order to provide adequate coverage for modeling. However, the sampling scale could also be tailored to meet regional conservation needs. Additionally, the NWRS must build institutional capacity to maintain databases and provide modeling products to meet regional conservation needs.

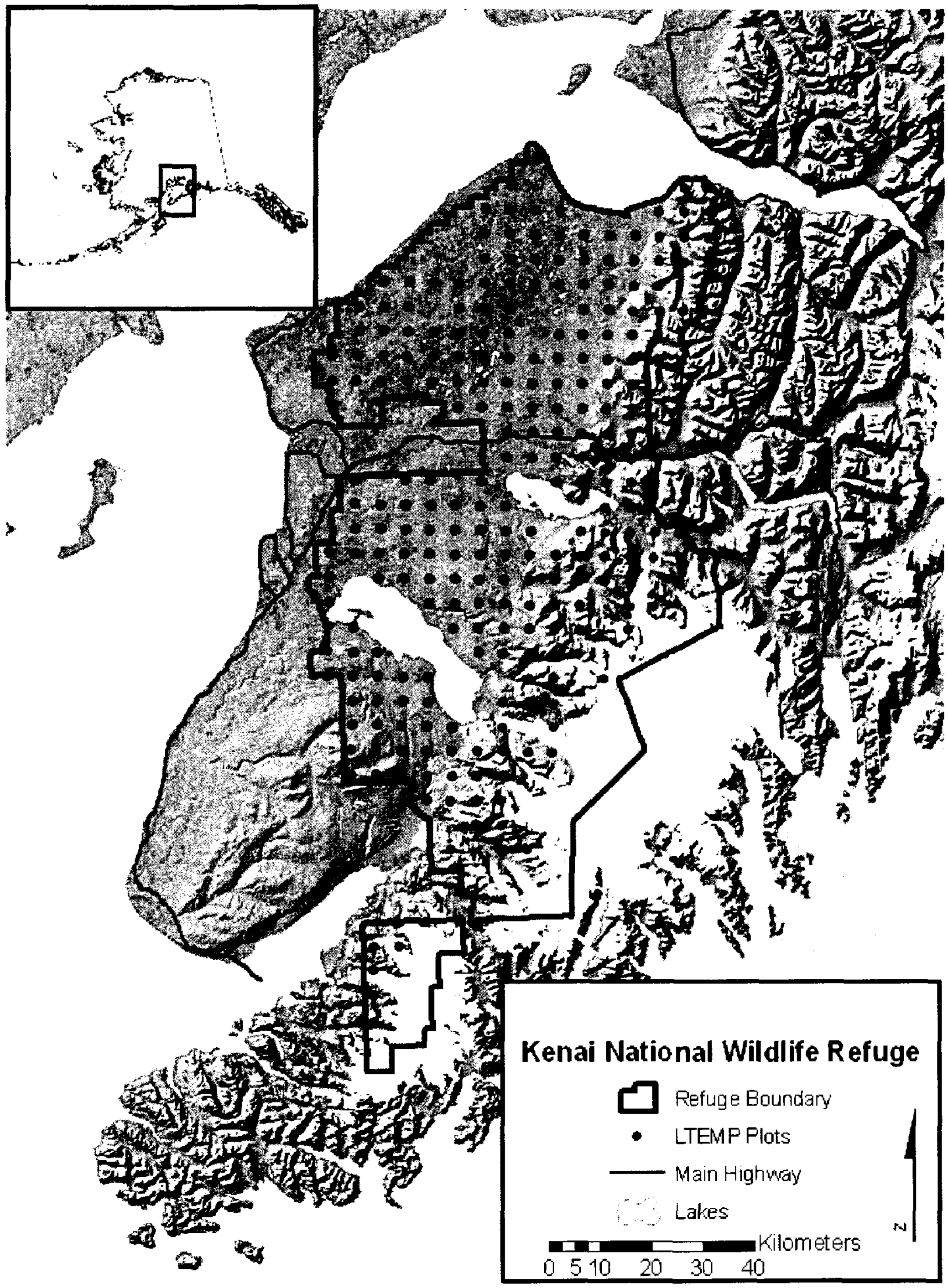

Figure 4. 1. Long-term Ecological Monitoring Program Plots. The Kenai National Wildlife Refuge in south-central Alaska. Plots are sampled for the refuge's Long-term Ecological Monitoring Program (LTEMP).

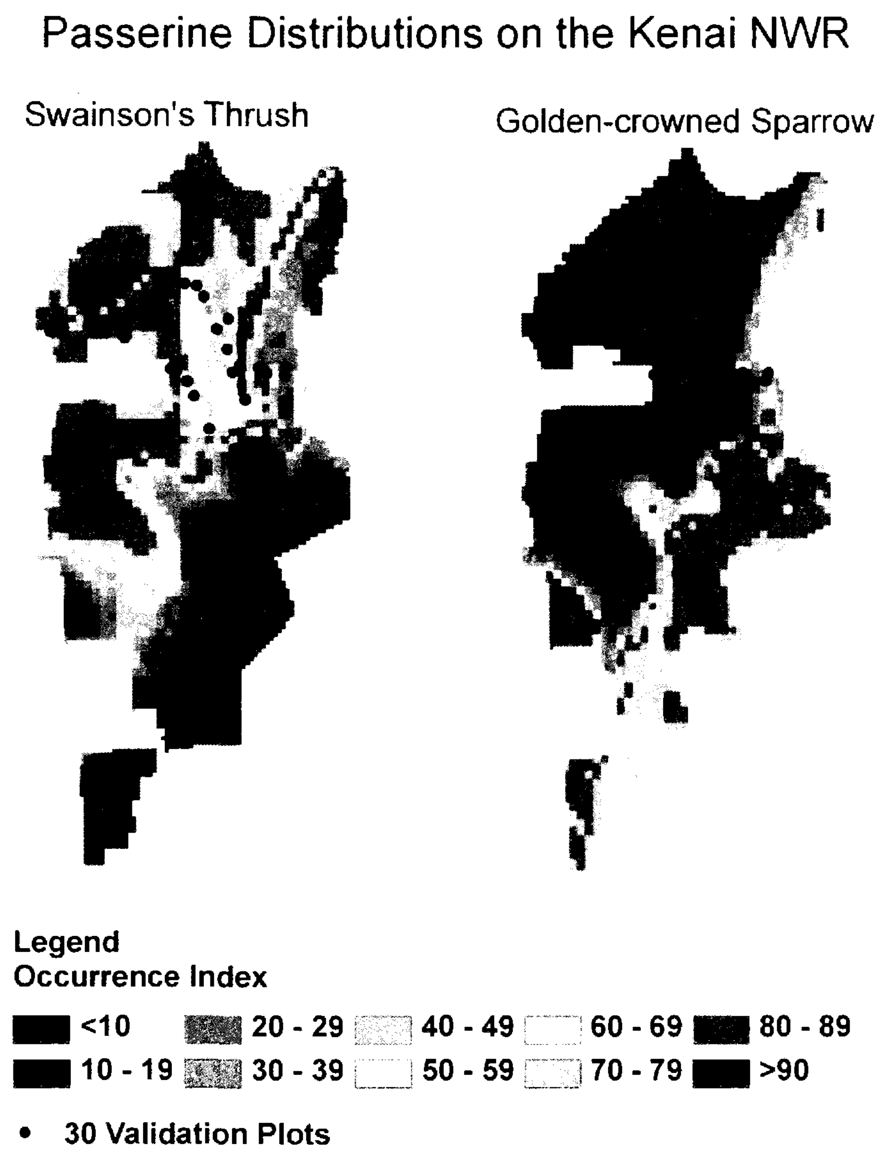

Figure 4. 2. Current Distributions. Current distributions of Swainson's thrush and golden-crowned sparrow on the Kenai National Wildlife Refuge. The 30 plots used for model validation are overlaid on distributions. The occurrence index represents the relative likelihood a species will be present and usually ranges from 0 to 100.

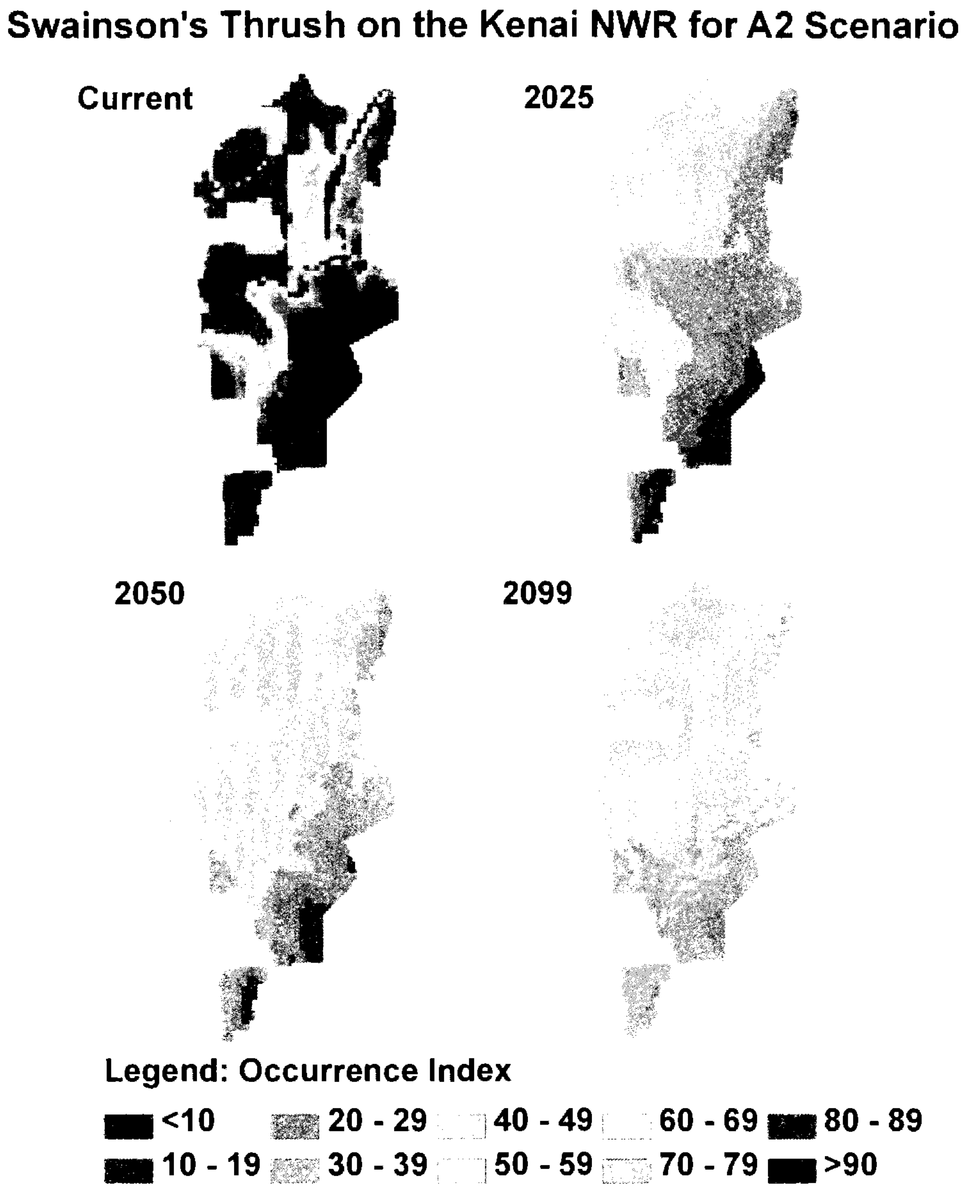

Figure 4. 3. Swainson's Thrush A2 Scenario Distribution. Current index of occurrence for Swaninson's thrush on the KENWR and projections for 2025, 2050, and 2099 based on the A2 emission scenario. The occurrence index represents the relative likelihood a species will be present and usually ranges from 0 to 100.

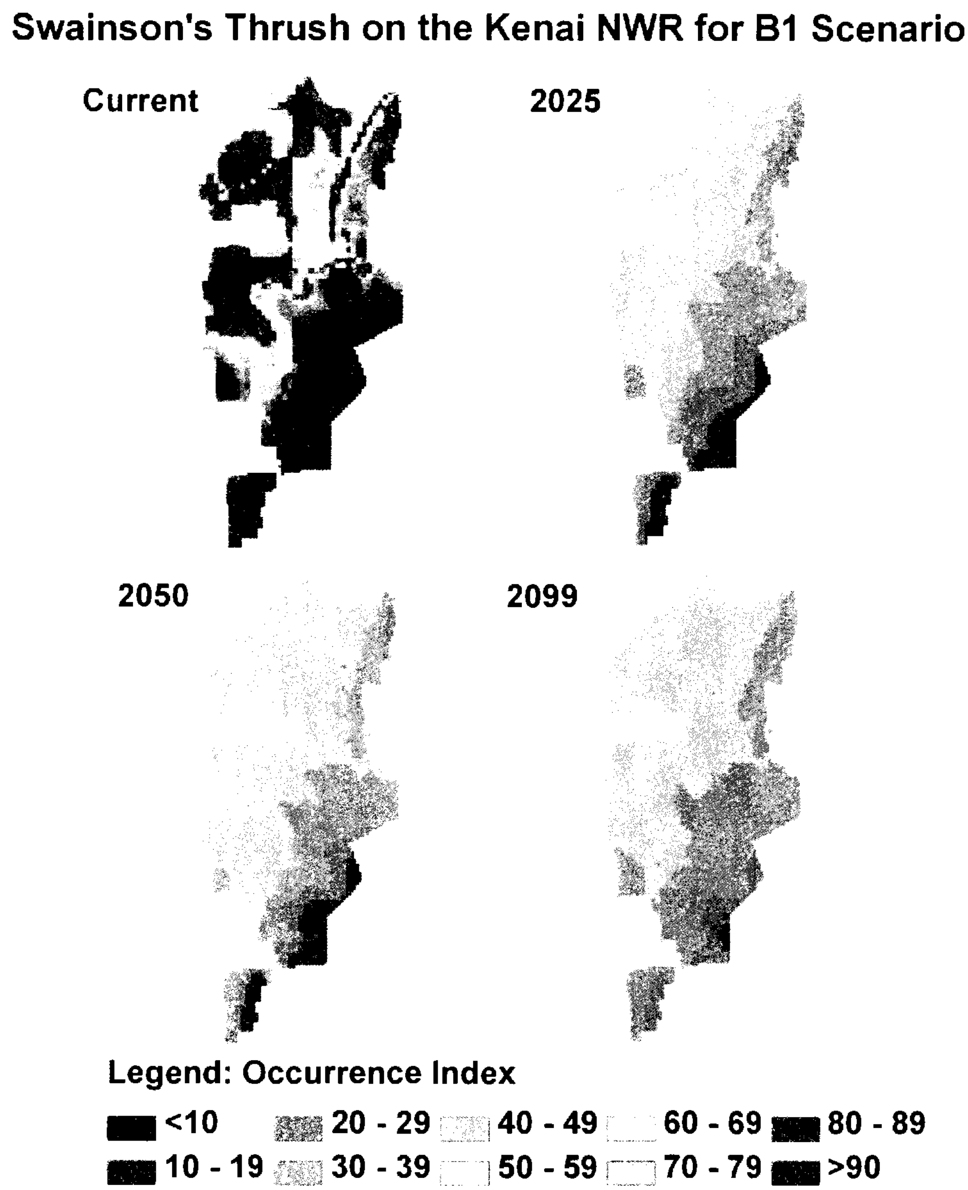

Figure 4. 4. Swainson's Thrush B1 Scenario Distribution. Current index of occurrence for Swaninson's thrush on the KENWR and projections for 2025, 2050, and 2099 based on the B1 emission scenario. The occurrence index represents the relative likelihood a species will be present and usually ranges from 0 to 100.

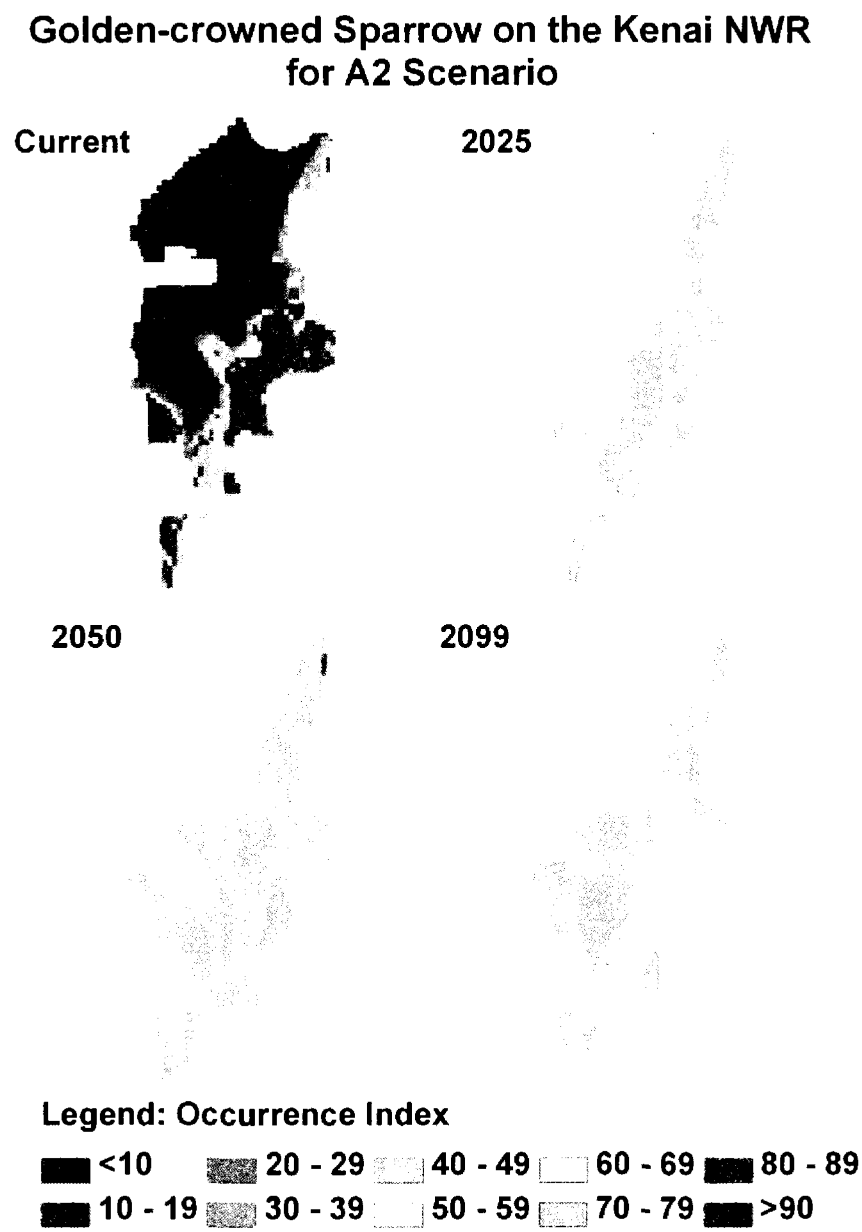

Figure 4. 5. Golden-crowned Sparrow A2 Scenario Distribution. Current index of occurrence for golden-crowned sparrow on the KENWR and projections for 2025, 2050, and 2099 based on the A2 emission scenario. The occurrence index represents the relative likelihood a species will be present and usually ranges from 0 to 100.

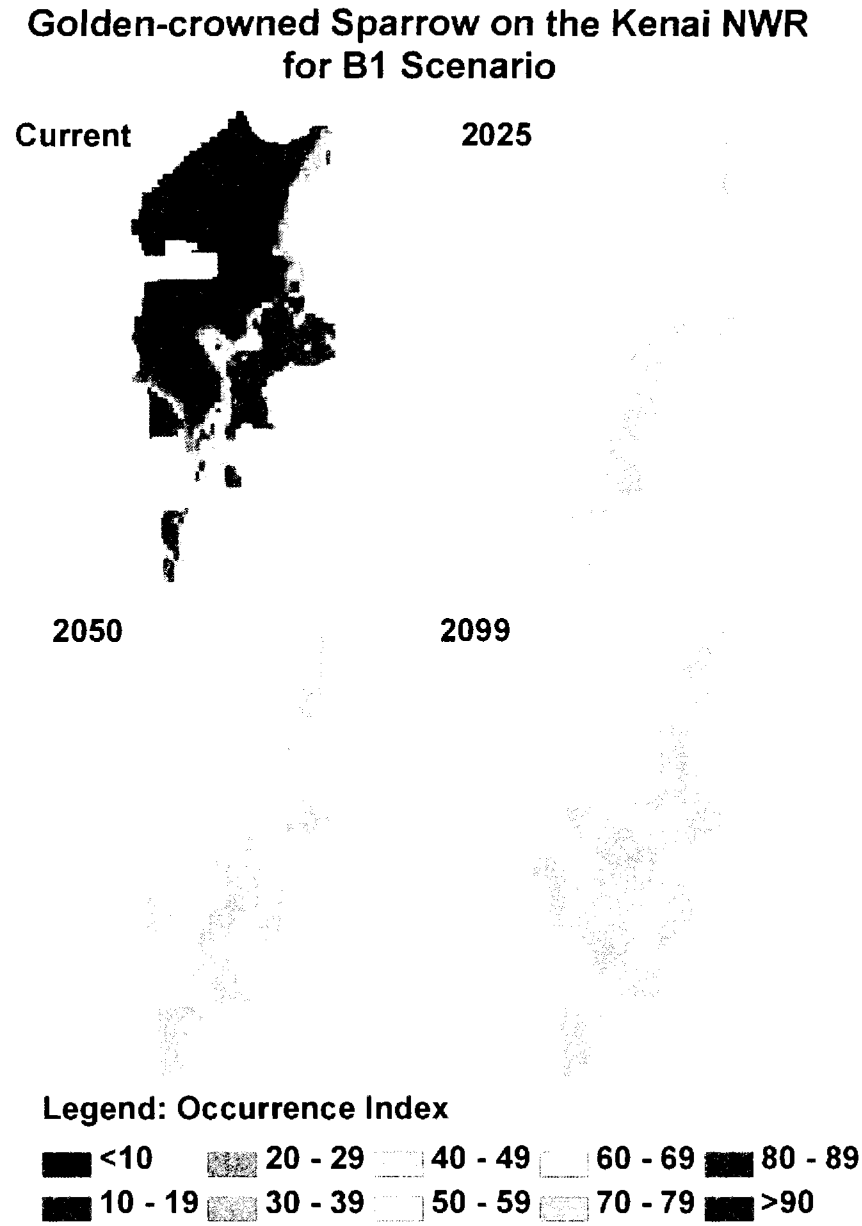

Figure 4. 6. Golden-crowned Sparrow B1 Scenario Distribution. Current index of occurrence for golden-crowned sparrow on the KENWR and projections for 2025, 2050, and 2099 based on the B1 emission scenario. The occurrence index represents the relative likelihood a species will be present and usually ranges from 0 to 100.

Table 4. 1. Prediction Variables. Prediction variables used to build species occurrence models. All layers derived from the 1-km resoiution historic data provided by Scenarios Network for Aiaska Pianning (SNAP).

Variable	Description
Monthly Temperature Mean (°C)	5-year mean for 1998 – 2002 average monthly air temperature. 12 layers; 1 for each month
Monthly Temperature Standard Deviation (°C)	Standard deviation for 5 years of average monthly air temperatures. 12 layers; 1 for each month
Monthly Precipitation Mean (mm)	5-year mean for 1998 – 2002 monthly precipitation. 12 layers; 1 for each month
Monthly Precipitation Standard Deviation (mm)	Standard deviation for 5 years of monthly precipitation. 12 layers; 1 for each month
Mean Annual Temperature (°C)	Yearly mean calculated from 12 monthly temperature means. 1 layer
Yearly Temperature Standard Deviation (°C)	Yearly standard deviation calculated from 12 monthly temperature means. 1 layer
Maximum Temperature (°C)	Maximum monthly 5-year temperature mean. 1 layer
Minimum Temperature (°C)	Minimum monthly 5-year temperature mean. 1 layer
Temperature Range (°C)	Maximum temperature minus minimum temperature. 1 layer
Mean Temperature of Wettest Quarter (°C)	Quarters were Dec-Feb, Mar-May, June-Aug, Sept-Nov. 3-month quarter mean of monthly temperatures for quarter with the most precipitation. 1 layer
Mean Temperature of Driest Quarter (°C)	Quarters were Dec-Feb, Mar-May, June-Aug, Sept-Nov. 3-month quarter mean of monthly temperatures for quarter with the least precipitation. 1 layer
Mean Temperature of Warmest Quarter (°C)	Quarters were Dec-Feb, Mar-May, June-Aug, Sept-Nov. 3-month quarter mean of monthly temperatures for the warmest quarter. 1 layer
Mean Temperature of Coldest Quarter (°C)	Quarters were Dec-Feb, Mar-May, June-Aug, Sept-Nov. 3-month quarter mean of monthly temperatures for the coldest quarter. 1 layer
Annual Precipitation (mm)	Sum of 5-year monthly precipitation means. 1 layer

Table 4. 2. Distribution Model Accuracy Assessment. Metrics summarize the predictive ability of Random Forest bioclimatic models for Swainson's thrush and golden-crowned sparrow distributions on the Kenai National Wildlife Refuge. The out-of-bag error rates are based on plots left out of the bootstrap sample during model building with the 255 plot data set. The validation data set consists of 30 independent plots.

			Out-of-Bag			Validation	
Species	ROC	LTEMP Plots Present n=255	Absent Correct %	Present Correct %	Validation Plots Present N=30	Absent Correct %	Present Correct %
Swainson's Thrush	0.827	131	71	77	25	80	80
Golden-crowned Sparrow	0.881	36	74	89	4	96	25

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CHAPTER 5 Conclusion

Climate change has been described as a wicked problem, complex at all levels (Ludwig 2001). Specifically, climate change is wicked because of the uncertainty about future conditions and the multiple, plausible perspectives regarding appropriate solutions. Technical expertise is required to assess the likelihood of future conditions. Scientists have focused on the uncertainty in future projections given incomplete system knowledge and unknowable future conditions (IPCC 2007). However, scientists and society also need to address the diverse perspectives about what future ecological conditions are acceptable and should be pursued.

When I entered my PhD program, with an undergraduate degree in biology and a master's in wildlife science, I was ill-equipped to address wicked problems. The biggest shortfall was my belief that there is one right answer to the world's environmental problems. Incognizant of belief systems (worldviews), I thought more information would force people to understand the dire need to protect biodiversity and ecosystems. However, more information will never resolve these types of issues because people filter information based on belief systems, discarding pieces that do not fit (Sabatier and Jenkins-Smith 1999, Weber and Word 2001)

Once I acknowledged the importance of belief systems, I began to examine my own as a scientist. For me, wildlife biology contains a narrative immersed in over-exploitation, extinction, and ill-fated tinkering. For example, a central story is the over-harvesting of the passenger pigeon (*Ectopistes migratorius*) which leads to its extinction by 1914. The passenger pigeon became a symbol of how greed could drive even the most abundant species to extinction (Blockstien 2002). Similarly, the NWRS began in response to extreme overharvesting of waterbirds in Florida to fuel the feather trade (Meretsky et al. 2006). Aldo Leopold, the father of modern wildlife biology, highlighted how human management often had unforeseen consequences with the example of the Kaibab deer overpopulation after wolf removal (Leopold 1943). Deer irrupted, decimated the vegetation, and then starved because humans could not understand complex ecological linkages.

I realized that my disbelief in our ability to manage complex ecological systems and skepticism about how our economic system values wildlife led me to default to natural systems as the best alternative. Indeed, other biologists and managers in the NWRS also seem to prefer the natural adaptation of species and ecosystems when climate change is inevitable. The United Nations Framework Convention on Climate Change (UNFCCC) also accepts this viewpoint. The UNFCCC Article 2 states the objective of the Convention is to stabilize greenhouse gases at levels and within a timeframe where ecosystems can adapt naturally to climate change. Often, the deference to natural adaptation is implicit in conservation discussions.

I now believe that conservation biologists and ecologists must explicitly develop their arguments regarding the values that we hope to preserve with naturally adapting ecosystems. Often scientists only convey study results in order to maintain objectivity. However, complex problems require that scientific facts be embedded in a cohesive narrative (Weber and Word 2001). Earth systems and wildlife habitats are now largely influenced by anthropogenic drivers (Vitousek et al. 1997, Ellis and Ramankutty 2008). As experts, we need to provide a framework of assumptions, data, and ethics that conveys the entirety of the belief system in order to highlight the importance of biodiversity.

Ecologists believe, and have evidence to support, that biodiversity is crucial to maintain because of its role in ecosystem functioning and productivity (Tilman et al. 1997). In the context of climate change, maintaining biodiversity becomes a bet-hedging strategy because common species often become less prevalent as environmental conditions change. In the new ecosystem state, species that were rare can become key components (Carpenter 2003). I believe ecologists prefer natural systems and natural adaptation because they would like to preserve the geographic integrity of historic population structures and therefore, the evolutionary lines that likely contain biodiversity. Additionally, natural systems and adaptation would protect biodiversity from further losses due to interactions with human populations. However, are natural systems always the best choice for maintaining biodiversity? Are there situations where humans could interact with ecosystems to increase biodiversity and the capacity of ecosystems to maintain functional properties and productivity?

Clearly, biodiversity has decreased in areas dominated by human influence; humans transform landscapes, usurp primary productivity, and use available fresh water resources (Vitousek et al. 1997). Both ecosystem processes and ecosystem resilience to climate change are affected by changes in biodiversity (Chapin et al. 2000). I believe the Fish and Wildlife Service (FWS) should be proactive in defining these issues for the public and explicit about assumptions in the proposed solutions. One of three basic objectives for the FWS is *"to assist in the development and application of an environmental stewardship ethics for our society, based on ecological principals, scientific knowledge of fish and wildlife, and a sense of moral responsibility"* (022 FW 1, FWM 327, 3/6/1998). Climate change provides an opportunity to shift the conceptualization of wildlife in policy and by the public. The NWRS has a history of key figures transforming ideas about wildlife problems and wildlife policy. Rachel Carson's book Silent Spring (Carson 1962) was an information package that informed and involved enough of the public to push for policy change. Aldo Leopold moved wildlife policy from sanctuaries that just need to not be violated by man into areas that needed active management (Leopold 1933). The problem of climate change has permeated through U.S. society due to information packages like Al Gore's 2005 film 'An Inconvenient Truth'. Concern about climate change presents a political window, or opportunity, to restructure wildlife policy. What values and messages should the FWS and NWRS convey?

The FWS and NWRS need to be explicit in their goals and the rationale for their goals, given the new problem of climate change. I believe that the FWS and NWRS should focus on: (1) ecosystem services, (2) adaptive management, and (3) open-access information.

5.1 ECOSYSTEM SERVICES

Ecosystem services links wildlife and environmental issues with human health and well-being (Millennium Ecosystem Assessment 2005). When environmental and human issues are considered separately, environmental entities must be argued to have intrinsic value, but it is difficult to elevate environmental concerns above human concerns based on their intrinsic value alone. Ecosystem services include provisioning services (food, water, energy), regulating services (carbon sequestration, pollination, decomposition, purification of water and air), supporting services (seed dispersal, nutrient cycling), and cultural services (recreation, scientific discovery, inspiration). NWRS lands could become integral components of landscapes, linked by partnerships with other land-owners, that provide ecosystem services to the regions in which they are embedded. In this context, biodiversity is an ecosystem service that helps to maintain ecosystem functioning with environmental change. Biodiversity is central to the mission of the NWRS (Public Law 105-57). Therefore, focusing on biodiversity and its role in regional ecosystem function would be a good fit for the agency and would provide a clear link to other human values.

We need a strong ethical debate about the role of biodiversity in regional landscapes because climate change brings new situations to navigate. For example, on the Kenai National Wildlife Refuge (KENWR), warming climatic conditions will likely melt ice and connect tundra islands (i.e., nunataks) that are embedded in glaciers. Plants on these ice-free islands are genetically distinct populations. Should managers maintain the isolation of these plants or should the genetic diversity be allowed to intermix with the main population?

With new habitats and climate conditions opening up geographically we will need to decide whether to seed new areas with biodiversity with the hopes of expanding diversity at the evolutionary leading edge. By evolutionary leading edge, I refer to the potential for rapid evolution in novel environmental conditions. For example, the invasive cane toad (*Chaunus [Bufo] marinus*) has expanded beyond measured physiological constraints when exposed to the hot climatic conditions in Australia (Urban et al. 2007). Presumably, rapid evolution in the new climate facilitated this expansion. Given the potential for species to change in new conditions, management decisions regarding which species should be moved, when, and to where could have profound and surprising consequences.

5.2 ADAPTIVE MANAGMENT

Adaptive management is an iterative process that uses management actions to learn about ecosystem functioning (Walters 1986). Managers continually try to generate hypotheses about system structure, test these hypotheses, and readjust management actions. Scott et al. (2008) have also suggested that adaptive management be a framework for NWRS adaptation actions. Climate change has the potential to restructure ecosystems in surprising ways. Therefore, managers need to continually look for opportunities to learn from the ecosystem. However, science does not fill the role of ethics in helping decide the right course of action.

Although conceptually useful, adaptive management has not been effectively used to gain insight about ecosystem behavior or to assess policy alternatives (Lee 1999). Adaptive management requires cost-intensive monitoring of targeted response variables (Walters 1997). The tendency to focus on monitoring a target species or resource can be dangerous because non-target impacts can be ignored. Additionally, the practice of adaptive management has focused on small-scale studies because they are methodologically feasible, even though small-scale studies may not scale-up or even be relevant to the large-scale management problem (Houlahan 1998).

5.3 OPEN-ACCESS INFORMATION

Although climate change is a pressing management problem, most managers in the United States currently lack the baseline information necessary to identify climate change impacts or project likely future conditions for planning (GAO 2007). Well-designed spatial monitoring programs linked with species distribution models provide a powerful tool to fill conservation knowledge gaps. Many disparate monitoring and inventory programs currently collect information regarding species occurrence or abundance, but their designs traditionally focus on aspatial parameter estimation. For accurate parameter estimation, the sample design centers on generating the sample size necessary to detect temporal changes in parameters and not on spatial, representative sampling or spatially explicit models. A grid-based system of dividing the globe, like the UTM system, could provide a framework that could be easily scaled and sub-sampled based on local monitoring needs. Spatially explicit designs and standards for integrated database management would greatly increase the utility and cost-effectiveness of monitoring programs.

The information in these integrated databases should be made freely and publicly available. Open-source databases, that are linked to decision-making processes, are necessary for transparent science-based management (Huettmann 2005). In addition, when agencies provide a data-rich context for citizens and interest groups, unique solutions to problems may become available (Fung and O'Rourke 2000).

5.4 RECOMMENDATIONS

Global climate change is a complex problem that will require new initiatives in the NWRS. I recommend that the NWRS should (1) develop a strategic adaptation plan, (2) link monitoring initiatives with modeling capacity, and (3) increase the capacity to learn about adaptation.

The development of a strategic adaptation plan requires the NWRS to define explicit management goals given a rapidly changing climate. I argue that the main goal for the NWRS should be to minimize extinction because biodiversity is an important ecosystem service. Minimizing extinction requires that NWRS lands be coordinated spatially and temporally in order to link refugia and transitioning areas. In addition, the strategic adaptation management plan should include a process of engagement for managers and biologists for consensus building and to ensure that the strategic adaptation plan can be used to contextualize refuges for Comprehensive Conservation Plan (CCP) development.

Distribution modeling is a useful approach that can provide information for developing a national adaptation plan. The NWRS needs to build the institutional capacity to maintain data and to provide modeling products. Monitoring initiatives should also be integrated with modeling efforts to be cost-effective.

Finally, some adaptation approaches are risky. Therefore, the NWRS needs to build capacity to learn and disseminate information from all management actions aimed to adapt to a rapidly changing climate. The NWRS could develop an institution to focus on adaptation research. Grant programs could also include requirements to disseminate information from funded adaptation actions, whether they are successes or failures.

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Appendix A

Spearman Correlation Matrices for Climate Change and Resilience Variables

Table A-1. Correlation of Climate Change Variables. Spearman correlation matrix of climate change variables.

	Minimum Temp. Change	Maximum Temp. Change	Average Temp. Trend	Precipitation Change	Sea Level Rise
Minimum Temp. Change	1.000	0.379	0.351	-0.069	0.129
Maximum Temp. Change	0.379	1.000	0.311	-0.180	-0.157
Average Temp. Trend	0.351	0.311	1.000	-0.236	0.504
Precipitation Change	-0.069	-0.180	-0.236	1.000	-0.085
Sea Level Rise	0.129	0.157	0.504	-0.085	1.000

Table A-2. Correlation of Resilience Variables. Spearman correlation matrix of resilience variables.

	Refuge Area	Latitudinal Range	Road Density in Buffer Only	Refuge Elevation Range
Refuge Area	1.000	0.807	-0.091	0.503
Latitudinal Range	0.807	1.000	-0.045	0.447
Road Density in Buffer Only	-0.091	-0.045	1.000	-0.011
Refuge Elevation Range	0.503	0.447	-0.011	1.000

Appendix B

List of Refuges Analyzed and the Scaled Temperature Change, Climate Change and Resilience Ranks

Refuge Name	Temperature Change Rate	Climate Change Rate	Resilience
ACE BASIN	40	53	46
AGASSIZ	81	55	65
ALAMOSA	54	35	41
ALASKA MARITIME	61	69	99
ALASKA PENINSULA	94	83	99
ALLIGATOR RIVER	28	39	67
AMAGANSETT	72	77	7
ANAHO ISLAND	87	51	63
ANAHUAC	20	61	49
ANAHUAC	46	72	70
ANKENY	62	72	31
ANTIOCH DUNES	58	37	4
APPERT LAKE	73	65	38
ARAPAHO	67	28	77
ARCHIE CARR	14	67	23
ARCTIC	100	80	99
ARDOCH	73	57	31
AROOSTOOK	50	62	60
ARROWWOOD	76	41	66
ARTHUR R. MARSHALL LOXAHATCHEE	43	58	37
ASH MEADOWS	80	54	84
ASSABET RIVER	51	68	31
ATCHAFALAYA	23	33	58
ATTWATER PRAIRIE CHICKEN	21	60	41
AUDUBON	61	35	49
BACA	38	29	84
BACK BAY	42	50	50
BALCONES CANYONLANDS	37	56	64
BALD KNOB	33	25	41

Appendix B Continued

Refuge Name	Temperature Change Rate	Climate Change Rate	Resilience
BAMFORTH	57	21	49
BANDON MARSH	57	72	33
BANKS LAKE	11	30	33
BASKETT SLOUGH	74	73	33
BAYOU COCODRIE	30	38	49
BAYOU SAUVAGE	10	45	49
BAYOU TECHE	11	49	53
BEAR BUTTE	55	31	34
BEAR LAKE	69	30	71
BEAR RIVER	67	46	70
BEAR VALLEY	56	57	54
BECHAROF	97	82	98
BENTON LAKE	66	35	66
BIG BOGGY	34	70	48
BIG BRANCH MARSH	17	52	39
BIG LAKE	42	42	38
BIG MUDDY	31	40	66
BIG OAKS	34	49	60
BIG STONE	52	46	54
BILL WILLIAMS RIVER	76	47	73
BITTER CREEK	82	65	78
BITTER LAKE	64	39	56
BLACK BAYOU LAKE	14	51	26
BLACK COULEE	85	37	59
BLACKBEARD ISLAND	21	52	60
BLACKWATER	50	51	59
BLOCK ISLAND	60	78	32
BLUE RIDGE	96	57	64
BOGUE CHITTO	24	55	45
BOMBAY HOOK	54	68	50
BON SECOUR	13	64	62
BOND SWAMP	15	31	48
BONE HILL	52	31	22
BOSQUE DEL APACHE	65	48	86
BOWDOIN	85	41	67
BOYER CHUTE	41	37	43

Appendix B Continued

Refuge Name	Temperature Change Rate	Climate Change Rate	Resilience
BRAZORIA	36	71	61
BRETON	19	65	59
BROWNS PARK	67	32	82
BRUMBA	43	42	41
BUENOS AIRES	68	48	84
BUFFALO LAKE	43	33	49
BUFFALO LAKE	55	44	54
CABEZA PRIETA	86	55	90
CACHE RIVER	34	37	63
CADDO LAKE	24	57	47
CAHABA RIVER	11	32	51
CALOOSAHATCHEE	30	65	2
CAMAS	74	42	55
CAMERON PRAIRIE	28	65	57
CAMP LAKE	71	41	54
CANAAN VALLEY	24	54	75
CANFIELD LAKE	71	47	42
CAPE MAY	46	46	39
CAPE MEARES	70	71	22
CAPE ROMAIN	14	52	64
CAROLINA SANDHILLS	32	37	60
CASTLE ROCK	32	75	37
CAT ISLAND	36	33	64
CATAHOULA	31	36	57
CEDAR ISLAND	25	39	61
CEDAR KEYS	25	46	41
CEDAR POINT	36	38	44
CHARLES M. RUSSELL	83	39	94
CHASE LAKE	70	47	59
CHASSAHOWITZKA	33	62	50
CHAUTAUQUA	23	34	55
CHICKASAW	34	41	68
CHINCOTEAGUE	39	61	56
CHOCTAW	32	35	47
CIBOLA	85	48	67
CLARENCE CANNON	47	42	40

Appendix B Continued

Refuge Name	Temperature Change Rate	Climate Change Rate	Resilience
CLARKS RIVER	35	47	47
CLEAR LAKE	49	43	81
COACHELLA VALLEY	71	44	41
COKEVILLE MEADOWS	51	26	74
COLD SPRINGS	66	39	41
COLDWATER RIVER	41	54	40
COLUMBIA	72	46	77
COLUSA	38	51	35
CONBOY LAKE	61	43	53
CONSCIENCE POINT	65	83	5
COPALIS	46	80	42
COTTONWOOD LAKE	72	44	37
CRAB ORCHARD	40	49	59
CRANE MEADOWS	88	52	46
CREEDMAN COULEE	77	42	59
CRESCENT LAKE	64	28	86
CROCODILE LAKE	51	64	53
CROSS CREEKS	30	51	50
CROSS ISLAND	46	68	60
CRYSTAL RIVER	33	65	29
CURRITUCK	40	43	60
CYPRESS CREEK	23	41	60
DAHOMEY	41	42	37
DAKOTA LAKE	51	37	44
D'ARBONNE	13	51	42
DEEP FORK	33	55	55
DEER FLAT	77	41	54
DELEVAN	37	56	40
DELTA	24	57	61
DES LACS	70	46	65
DESERT	92	52	79
DESOTO	33	36	33
DETROIT RIVER	24	32	46
DON EDWARDS SAN FRANCISCO BAY	64	63	51
DRIFTLESS AREA	36	45	47
DUNGENESS	77	59	44

Appendix B Continued

Refuge Name	**Temperature Change Rate**	**Climate Change Rate**	**Resilience**
EASTERN NECK	45	70	33
EASTERN SHORE OF VIRGINIA	37	55	46
EDWIN B. FORSYTHE	56	65	49
EGMONT KEY	24	43	35
ELIZABETH ALEXANDRA MORTON	62	82	18
ELLICOTT SLOUGH	43	69	6
EMIQUON	18	31	51
ERIE	49	38	55
EUFAULA	26	33	60
FALLON	85	45	58
FARALLON	48	73	36
FEATHERSTONE	46	63	16
FELSENTHAL	29	52	67
FERN CAVE	22	26	57
FISH SPRINGS	59	37	79
FISHERMAN ISLAND	39	55	44
FLATTERY ROCKS	65	88	29
FLINT HILLS	50	38	50
FLORENCE LAKE	69	41	54
FLORIDA PANTHER	45	65	46
FORT NIOBRARA	49	34	79
FOX RIVER	62	53	30
FRANKLIN ISLAND	37	63	31
FRANZ LAKE	58	71	39
GLACIAL RIDGE	67	53	65
GRAND BAY	21	64	36
GRAND COTE	32	32	47
GRAVEL ISLAND	62	71	29
GRAYS HARBOR	63	61	42
GRAYS LAKE	67	48	82
GREAT BAY	65	85	28
GREAT DISMAL SWAMP	34	43	48
GREAT MEADOWS	59	74	34
GREAT RIVER	19	30	44
GREAT SWAMP	66	52	39
GREAT WHITE HERON	18	38	66

Appendix B Continued

Refuge Name	Temperature Change Rate	Climate Change Rate	Resilience
GREEN BAY	60	45	28
GRULLA	48	37	52
GUADALUPE-NIPOMO DUNES	40	56	46
HAGERMAN	50	59	43
HAILSTONE	70	36	59
HAKALAU FOREST	26	48	86
HALFBREED LAKE	71	36	64
HALF-WAY LAKE	64	46	26
HAMDEN SLOUGH	81	59	39
HANALEI	8	43	58
HANDY BRAKE	14	51	35
HARBOR ISLAND	80	79	51
HARRIS NECK	19	47	51
HART MOUNTAIN	56	43	93
HATCHIE	28	43	47
HAVASU	82	45	71
HEWITT LAKE	85	39	37
HIDDENWOOD	71	37	38
HILLSIDE	30	47	56
HOBART LAKE	42	32	40
HOBE SOUND	33	75	12
HOLLA BEND	35	47	37
HOLT COLLIER	30	37	44
HOPPER MOUNTAIN	58	66	56
HORICON	44	44	49
HULEIA	8	44	7
HUMBOLDT BAY	53	73	45
HURON	41	53	34
HUTCHINSON LAKE	55	37	40
HUTTON LAKE	51	19	45
IMPERIAL	83	50	85
INNOKO	99	78	97
IROQUOIS	65	66	45
ISLAND BAY	34	68	28
IZEMBEK	46	61	97
J.CLARK SALYER	69	48	69

Appendix B Continued

Refuge Name	Temperature Change Rate	Climate Change Rate	Resilience
J.N. 'DING' DARLING	38	72	50
JAMES CAMPBELL	8	47	48
JAMES RIVER	63	53	42
JOHN H. CHAFEE	70	77	33
JOHN HAY	58	72	7
JOHN HEINZ AT TINICUM	46	51	19
JOHN W. AND LOUISE SEIER	45	26	59
JOHNSON LAKE	72	55	55
JULIA BUTLER HANSEN	62	61	47
KAKAHAIA	8	50	31
KANUTI	100	73	97
KARL E. MUNDT	29	28	56
KARNER BLUE BUTTERFLY	52	69	4
KEALIA POND	8	52	22
KELLYS SLOUGH	69	56	37
KENAI	94	82	96
KERN	70	52	42
KEY CAVE	31	53	28
KEY WEST	10	36	67
KILAUEA POINT	8	52	30
KIRTLANDS WARBLER	36	40	50
KIRWIN	17	37	53
KLAMATH MARSH	75	46	73
KODIAK	88	81	98
KOFA	87	48	92
KOOTENAI	72	59	54
KOYUKUK	99	75	98
LACASSINE	16	59	61
LACREEK	46	43	76
LAGUNA ATASCOSA	48	58	51
LAKE ALICE	48	48	50
LAKE ANDES	35	31	48
LAKE GEORGE	69	44	55
LAKE ILO	87	41	54
LAKE ISOM	30	38	31
LAKE MASON	60	37	78

Appendix B Continued

Refuge Name	Temperature Change Rate	Climate Change Rate	Resilience
LAKE NETTIE	54	33	41
LAKE OPHELIA	36	42	61
LAKE OTIS	78	44	36
LAKE PATRICIA	63	31	47
LAKE THIBADEAU	73	35	61
LAKE UMBAGOG	61	63	82
LAKE WALES RIDGE	8	43	47
LAKE WOODRUFF	28	45	43
LAKE ZAHL	59	32	47
LAMBS LAKE	58	47	39
LAMESTEER	81	34	49
LAS VEGAS	64	41	57
LEE METCALF	77	45	32
LESLIE CANYON	72	43	83
LEWIS AND CLARK	49	69	56
LITTLE GOOSE	50	46	35
LITTLE PEND OREILLE	68	71	77
LITTLE RIVER	31	53	46
LITTLE SANDY	16	47	31
LOGAN CAVE	28	36	11
LORDS LAKE	51	40	40
LOST LAKE	61	39	43
LOST TRAIL	67	38	57
LOSTWOOD	65	38	73
LOWER HATCHIE	25	40	64
LOWER KLAMATH	54	52	66
LOWER RIO GRANDE VALLEY	51	55	62
LOWER SUWANNEE	19	42	55
MACKAY ISLAND	40	44	49
MALHEUR	50	45	89
MANDALAY	35	39	32
MAPLE RIVER	58	37	42
MARAIS DES CYGNES	35	25	44
MARIN ISLANDS	51	69	10
MARTIN	43	66	46
MASHPEE	48	67	37

Appendix B Continued

Refuge Name	**Temperature Change Rate**	**Climate Change Rate**	**Resilience**
MASON NECK	43	62	21
MASSASOIT	53	68	4
MATHEWS BRAKE	31	31	45
MATLACHA PASS	32	72	8
MATTAMUSKEET	36	42	56
MAXWELL	40	31	52
MCFADDIN	20	64	65
MCKAY CREEK	67	39	43
MCLEAN	67	36	42
MCNARY	64	47	57
MEDICINE LAKE	86	34	78
MERCED	69	53	39
MEREDOSIA	24	16	42
MERRITT ISLAND	42	66	54
MICHIGAN ISLANDS	39	71	45
MIDDLE MISSISSIPPI RIVER	41	43	51
MILLE LACS	71	41	25
MINGO	32	44	61
MINIDOKA	64	35	70
MINNESOTA VALLEY	69	56	47
MISSISQUOI	60	65	34
MISSISSIPPI SANDHILL CRANE	17	60	43
MOAPA VALLEY	76	50	32
MODOC	55	40	53
MONOMOY	47	67	47
MONTE VISTA	39	35	62
MONTEZUMA	45	48	53
MOODY	23	69	46
MOOSEHORN	51	73	77
MORGAN BRAKE	33	44	61
MORTENSON LAKE	45	17	48
MOUNTAIN LONGLEAF	37	38	50
MULESHOE	55	29	47
MUSCATATUCK	49	58	40
NANSEMOND	38	39	8
NANTUCKET	59	71	33

Appendix B Continued

Refuge Name	Temperature Change Rate	Climate Change Rate	Resilience
NATIONAL BISON RANGE	78	39	74
NATIONAL ELK	87	37	79
NATIONAL KEY	24	45	67
NEAL SMITH	36	23	50
NECEDAH	59	41	62
NESTUCCA BAY	66	76	53
NINE-PIPE	82	41	38
NINIGRET	66	77	30
NISQUALLY	53	47	47
NOMANS LAND ISLAND	67	74	40
NORTH PLATTE	44	16	52
NOWITNA	99	71	97
NOXUBEE	23	51	73
OCCOQUAN BAY	43	60	3
OHIO RIVER ISLANDS	39	44	47
OKEFENOKEE	20	34	62
OPTIMA	38	35	46
OREGON ISLANDS	55	68	37
OTTAWA	34	44	41
OURAY	95	42	71
OVERFLOW	14	47	53
OXBOW	42	64	32
OYSTER BAY	60	62	35
OZARK CAVEFISH	17	37	11
OZARK PLATEAU	33	48	55
PABLO	79	40	47
PAHRANAGAT	80	53	72
PANTHER SWAMP	31	50	56
PARKER RIVER	58	79	42
PASSAGE KEY	29	46	31
PATHFINDER	76	36	72
PATOKA RIVER	27	47	54
PATUXENT	53	54	45
PEA ISLAND	18	49	64
PEARL HARBOR	8	43	6
PEE DEE	29	33	50

Appendix B Continued

Refuge Name	Temperature Change Rate	Climate Change Rate	Resilience
PELICAN ISLAND	17	68	20
PETIT MANAN	34	58	64
PIEDMONT	29	38	70
PIERCE	48	67	50
PILOT KNOB	41	38	20
PINCKNEY ISLAND	28	54	23
PINE ISLAND	38	74	33
PINELLAS	24	46	6
PIXLEY	72	52	45
PLEASANT LAKE	42	45	47
PLUM TREE ISLAND	28	41	22
POCOSIN LAKES	25	33	61
POND CREEK	30	53	61
POND ISLAND	40	76	28
PORT LOUISA	33	28	72
PRESQUILE	64	54	32
PRETTY ROCK	82	33	46
PRIME HOOK	65	61	38
PROTECTION ISLAND	81	62	49
QUILLAYUTE NEEDLES	53	73	31
QUIVIRA	40	44	55
RABB LAKE	26	31	28
RACHEL CARSON	27	70	46
RAPPAHANNOCK RIVER VALLEY	45	59	68
RED RIVER	42	62	60
REELFOOT	29	45	53
RICE LAKE	85	52	64
RICE LAKE -SANDSTONE UNIT	60	50	47
RIDGEFIELD	79	73	30
ROANOKE RIVER	37	41	55
ROCK LAKE	50	47	51
ROCKY MOUNTAIN ARSENAL	54	23	45
ROSE LAKE	56	49	47
RUBY LAKE	62	53	85
RYDELL	68	52	34
SABINE	28	66	67

Appendix B Continued

Refuge Name	Temperature Change Rate	Climate Change Rate	Resilience
SACHUEST POINT	63	79	11
SACRAMENTO	45	61	47
SACRAMENTO RIVER	44	59	52
SADDLE MOUNTAIN	71	45	87
SALINAS RIVER	56	66	36
SALT PLAINS	20	49	53
SAN ANDRES	83	52	87
SAN BERNARD	42	71	62
SAN BERNARDINO	67	44	64
SAN DIEGO	73	50	61
SAN JOAQUIN RIVER	72	59	42
SAN JUAN ISLANDS	75	63	43
SAN LUIS	51	52	40
SAN PABLO BAY	67	78	42
SAND LAKE	62	36	60
SANTA ANA	50	52	20
SANTEE	24	43	37
SAUTA CAVE	11	20	13
SAVANNAH-PINCKNEY S	15	30	46
SCHOOL SECTION LAKE	37	36	28
SEAL BEACH	67	58	12
SEAL ISLAND	35	54	35
SEATUCK	76	66	9
SEEDSKADEE	43	25	73
SELAWIK	99	80	98
SENEY	66	40	83
SEQUOYAH	38	53	64
SEVILLETA	90	52	77
SHAWANGUNK GRASSLANDS	41	56	18
SHELDON	51	34	94
SHELL KEYS	8	36	34
SHELL LAKE	68	37	56
SHERBURNE	66	51	52
SHEYENNE LAKE	63	38	40
SHIAWASSEE	21	46	35
SIBLEY LAKE	60	47	46

Appendix B Continued

Refuge Name	Temperature Change Rate	Climate Change Rate	Resilience
SILETZ BAY	66	79	31
SILVER LAKE	44	44	45
SILVIO O. CONTE	63	66	66
SLADE	74	49	44
SNYDER LAKE	44	42	38
SONNY BONO SALTON SEA	65	42	52
SPRINGWATER	55	30	36
SQUAW CREEK	27	17	54
ST. CATHERINE CREEK	28	36	63
ST. JOHNS	37	59	30
ST. MARKS	6	43	69
ST. VINCENT	24	64	54
STEIGERWALD LAKE	73	51	40
STEWART B. MCKINNEY	63	64	27
STEWART LAKE	79	31	42
STILLWATER	84	45	81
STONE LAKES	70	61	34
STONEY SLOUGH	45	32	42
STORM LAKE	53	44	30
STUMP LAKE	59	49	24
SULLYS HILL	53	43	55
SUNBURST LAKE	60	33	48
SUNKHAZE MEADOWS	26	37	58
SUPAWNA MEADOWS	45	63	25
SUSQUEHANNA	66	83	6
SUTTER	73	64	22
SWAN LAKE	39	32	49
SWAN RIVER	72	43	59
SWANQUARTER	26	41	62
SWEETWATER MARSH	54	52	9
TALLAHATCHIE	40	51	45
TAMARAC	74	55	75
TARGET ROCK	53	61	5
TEN THOUSAND ISLANDS	38	69	58
TENNESSEE	37	53	67
TENSAS RIVER	34	56	63

Appendix B Continued

Refuge Name	**Temperature Change Rate**	**Climate Change Rate**	**Resilience**
TETLIN	98	75	98
TEWAUKON	52	45	57
TEXAS POINT	18	66	52
THACHER ISLAND	40	46	23
THREE ARCH ROCKS	70	73	28
TIJUANA SLOUGH	46	47	20
TISHOMINGO	38	57	56
TOGIAK	95	81	99
TOMAHAWK	45	34	31
TOPPENISH	70	46	52
TREMPEALEAU	69	57	47
TRINITY RIVER	20	62	61
TRUSTOM POND	67	79	26
TUALATIN RIVER	74	68	34
TULE LAKE	61	49	75
TURNBULL	47	42	65
TWO PONDS	51	36	2
TWO RIVERS	35	43	39
TYBEE	39	68	34
UL BEND	73	35	89
UMATILLA	54	37	62
UNION SLOUGH	50	47	39
UPPER KLAMATH	66	49	60
UPPER OUACHITA	21	53	58
UPPER SOURIS	57	35	68
VALENTINE	36	16	89
WACCAMAW	15	59	40
WALLKILL RIVER	44	57	45
WALLOPS ISLAND	38	65	46
WAPACK	41	66	45
WAPANOCCA	22	34	41
WAR HORSE	84	43	67
WASHITA	34	54	55
WASSAW	31	59	62
WATERCRESS DARTER	20	29	2
WAUBAY	46	42	56

Appendix B Continued

Refuge Name	Temperature Change Rate	Climate Change Rate	Resilience
WERTHEIM	70	69	23
WEST SISTER ISLAND	31	23	35
WHEELER	18	36	56
WHITE LAKE	82	41	44
WHITE RIVER	37	28	71
WHITTLESEY CREEK	90	64	27
WICHITA MOUNTAINS	46	56	70
WILD RICE LAKE	51	46	33
WILLAPA	58	72	74
WILLIAM L. FINLEY	50	69	54
WILLOW LAKE	30	34	54
WINTERING RIVER	66	42	30
WOLF ISLAND	16	53	53
WOOD LAKE	57	46	28
YAZOO	24	41	53
YUKON DELTA	98	82	99
YUKON FLATS	99	74	98

Appendix C

Approval Letter from Institutional Review Board

(907) 474-7800
(907) 474-5444 fax
fyirb@uaf.edu
www.uaf.edu/irb

UAF
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FAIRBANKS

Institutional Review Board

909 N Koyukuk Dr. Suite 212, P.O. Box 757270, Fairbanks, Alaska 99775-7270

February 15, 2007

To: Amy Lovecraft, Ph.D
Principal Investigator

From: Bridget Stockdale, Research Integrity Administrator
Office of Research Integrity

Re: IRB Protocol Application

Thank you for submitting the IRB protocol application identified below. I have administratively reviewed this protocol and determined that it meets the requirements specified in federal regulation for exempt research under 45 CFR 46.101(b)(2). Therefore, I am pleased to inform you that your protocol has been approved.

Protocol #:	07-07
Title:	*A Survey of Management Strategies Linking Global Change to Decision-making in the National Wildlife Refuge System*
Level:	Exempt
Received:	January 31, 2007 (orig) February 8, 2007 (rev)
Approved:	February 15, 2007

Exempt research does not require annual continuing review, but please submit any modifications or changes to this protocol to ***fyirb@uaf.edu*** *for administrative review. Modification Request Forms are available on the IRB website* ***(http://www.uaf.edu/irb/Forms.htm)****. Please contact the Office of Research Integrity if you have any questions regarding IRB policies or procedures.*

Appendix D

Example Questionnaire

Introduction & Invitation to Participate in Study:

Climatic changes, whether human induced or naturally occurring, will provide new challenges for National Wildlife Refuge System employees working to maintain the biological integrity, diversity and environmental health of the System. In 2001, former Secretary of the Interior Bruce Babbitt directed each bureau in the Department of Interior to "consider and analyze potential climate change impacts when undertaking long-range planning exercises" (Secretarial Order No. 3226). However, little guidance has been provided in how to accomplish Secretarial Order No. 3226 (2007 GAO Report; Climate Change: Agencies Should Develop Guidance for Addressing the Effects on Federal Land and Water Resources).

You are being invited to fill out a questionnaire as part in a University of Alaska study. The purpose of this questionnaire is to understand whether and how System employees think refuges should address climate change impacts. If you decide to take part, **the questionnaire should take less than 30 minutes to complete.**

Risks and Benefits of Being in the Study:

The risks to you if you take part in this study are negligible. While there is no direct benefit from taking part in this study, your participation in this research will help clarify how refuge employees define the responsibilities of the National Wildlife Refuge System if and when the agency faces management decisions related to the impacts from global climate change.

Confidentiality:

Any information obtained about you will be kept strictly confidential. I will protect your confidentiality by coding your information with a number so no one can trace your answers to your name or refuge, properly disposing of computer sheets and other papers, limiting access to identifiable information, and storing research records in our faculty offices. The data derived from this study could be used in reports, presentations, and publications but you or your refuge will not be individually identified, without your permission. Do note that there are limitations to the confidentiality that can be granted to you in cases of criminal wrongdoing or imminent harm to yourself or others.

Voluntary Nature of the Study:

Your decision to take part in the study is voluntary. You are free to choose not to take part in the study or to stop taking part at any time without any penalty to you.

Contacts and Questions:

If you have any questions, you may contact Dawn Magness, 211A Irving I, Department of Biology and Wildlife, University of Alaska, Fairbanks, AK, 99775, 907-474-7568, dawn.magness@uaf.edu.

If you have questions or concerns about your rights as a research subject, please contact the Research Coordinator in the Office of Research Integrity at 474-7800 (Fairbanks area) or 1-866-876-7800 (outside the Fairbanks area) or fyirb@uaf.edu. This study has been approved as IRB Protocol # 07-07.

Statement of Consent:

By returning this questionnaire you are agreeing that (1) you understand the procedures described above, (2) that your questions have been answered to your satisfaction, and (3) that you agree to participate in this study.

In advance, thank you very much for your participation.

1.) What is the name of the refuge(s) where you are currently employed?

Refuge:

2.) What category best summarizes the primary establishment purpose of your refuge(s)?

- Conservation of migratory birds
- Conservation of endangered and/or threatened species
- Development and conservation of fish and/or wildlife resources
- Conservation of fish and wildlife populations and habitats in their natural diversity
- I don't know
- Other

3.) Is your refuge part of a complex?

Yes No I don't know

4.) What is the job series of your current position?

485 401 404 408 486 I don't know Other

5.) How long have you worked at this refuge?

< 1 year 1-5 years 5-10 years 10-20 years > 20 years

6.) How long have you worked in the National Wildlife Refuge System?

< 1 year 1-5 years 5-10 years 10-20 years > 20 years

7.) Have you worked in other Regions as a Service employee? Yes No

8.) How many permanent biologists or biological technicians are currently employed at your refuge? Please include yourself if you are a biologist or biotech.

0 1 2 3 4 5 6 >6

9.) What is your educational background? Please list all degrees held.

	Year	Degree	Field of Study (i.e. Biology, Statistics)
Degree 1:			
Degree 2:			
Degree 3:			
Degree 4:			

10.) Has your refuge or complex done a Comprehensive Conservation Plan (CCP)?

- Yes **Go to Next Question**
- No **Skip to Question 15**
- In CCP Process **Go to Next Question**

11.) Was climate change mentioned generally in the CCP?

- Yes
- No
- Have not completed draft
- I don't know

12.) Was climate change identified as an issue during scoping for the CCP?

- Yes
- No
- Have not completed scoping
- I don't know

13.) Did the vision statement and/or any goals in the CCP deal specifically with climate change mitigation, climate change education or an impact of climate change?

- Yes
- No
- Have not completed goals
- I don't know

14.) Were any alternatives in the CCP formulated around climate change impacts?

- Yes
- No
- Have not completed alternatives
- I don't know

15.) Is climate change included in other management documents for your refuge, such as fire management plans or habitat management plans?

- Yes (please list below) **Go to Next Question**
- No **Skip to Question 18**
- I don't know **Skip to Question 18**

List Management Documents

16.) In the management document(s) that included climate change, was climate change mentioned generally?

- Yes
- No
- Yes in some, but not all
- I don't know

17.) In the management document(s) that included climate change, does an impact of climate change result in a management response?

- Yes
- No
- Yes in some, but not all
- I don't know

18.) Regardless of how planning documents refer or don't refer to climate change, do you personally think that climate change is impacting resources on your refuge?

- Yes **Go to Next Question**
- No **Skip to Question 22**
- I don't know **Skip to Question 22**

19.) What climate change impacts do you think are currently occurring on your refuge? Please mark all that apply.

- Changes to phenology; changes in timing of flowering, breeding, or migration
- Changes to local weather patterns including extreme weather events
- Changing demographics of species of concern
- Changes in erosion rates
- Changes in frequency or duration of disturbances like fires
- Wetland drying
- Desertification
- Increases in exotic, invasive, or injurious species
- Hydrological change including changes in water volume and timing of hydrological events
- Shifts in species distributions
- Saltwater inundation or intrusion (sea-level rise)
- Habitat changes like rising treeline or the decline of historically dominant tree species
- Other(s) ______________________

20.) In your opinion, were the climate change impacts you identified as important in Question 20 adequately addressed in your refuge's CCP?

- CCP not completed
- Yes
- No
- I don't know

21.) How have climate change impacts been documented on your refuge? Please mark all that apply.

- [ ] Impacts have not been documented
- [ ] Anecdotal observations
- [ ] Unpublished refuge data
- [ ] Published studies or theses/dissertations on refuge lands
- [ ] Scientific literature on similar resources, but studied elsewhere
- [ ] Other(s) ____________________

22.) In your opinion, does your refuge need Regional or National guidance about if and how climate change impacts should be managed?

( ) Yes ( ) No ( ) I don't know

23.) Please order the following 5 general drivers of landscape change, occurring on refuge or in surrounding lands, from the most influential on your refuge (1) to the least influential (5).

- [ ] Landscape change and land-use conversion including, but not limited to urbanization
- [ ] Climate change
- [ ] Increasing influence of invasive, exotic, or injurious species
- [ ] Over-exploitation of resources including hunting, recreation demands, or extractive resource use
- [ ] Pollution including contaminants

24.) In your opinion, when managing the impacts of climate change, should climate change be treated as primarily as a natural process or as an anthropogenic process?

( ) Natural ( ) Anthropogenic ( ) Not relevant for management ( ) I don't know

Please read the following 7 stories about conservation issues that refuges may face in the future. These issues should be treated as stories because I am interested in your general philosophy about best conservation practices and not in the complexities of detailed case studies.

All other factors held equal (i.e. cost, public support), please choose the management response that you, as a Service employee, believe would best support the mission of the National Wildlife Refuge System. In some cases, you may find aspects of both management responses appealing. Please choose the response that you believe is best overall.

(1) The northern spotted owl is a threatened species that is restricted to old-growth forests in the Pacific Northwest. Northern spotted owls are displaced from occupied territories when barred owls are present. Barred owls were historically restricted to eastern North America, but have extended their range westward across Canada to British Columbia. From British Columbia, the barred owl range continued to expand south into the Pacific Northwest and north to southeast Alaska. Among other factors, climate change may have facilitated the range expansion of barred owls. Future climatic change may cause barred owl populations to increase at the expense of the spotted owl population.

- Barred owls should not be considered an invasive species in the historic range of northern spotted owl because barred owls are expanding their range without human assistance. Allow barred owl populations to increase as spotted owl populations decline. Focus effort of reducing other stressors to northern spotted owl populations like forest management practices that reduce old-growth habitat.

- Consider barred owl to be an invasive species within the historic range of northern spotted owls. Engage in efforts like trapping to control barred owl populations within the historic range of northern spotted owl.

(2) Predicted levels of sea level rise indicate complete inundation (within the next 50 years) of an island which includes several unique habitat types that support endemic species of amphibians, arthropods and plants.

- Construct levee, dyke, or other engineered structures to protect island.
- Allow island to be inundated. Conduct translocations of endemic species to other islands or mainland areas with similar habitat even though these areas are outside of the historic range for these species.

(3) The wetlands of the prairie pothole region provide important breeding habitat for canvasback ducks. Temperature and rainfall affect wetland condition. Wetland condition affects the size of the breeding population in a given area and the reproductive success of canvasbacks. Climate change projections predict that warming temperatures and changing precipitation patterns will result in fewer wetlands and greater annual variability in surface water. These changes are linked to lowered reproductive success due to factors like lower nesting success, smaller clutch sizes, and lower brood survival. Your refuge in the prairie pothole region has been subject to drought conditions for several years leading to a reduction in high quality wetland habitat and reduced canvasback numbers.

- Allow wetland conditions within your refuge to change with the changing climate. Allow the canvasback population within the refuge boundary to decline to levels that can be supported by wetland conditions in the future. Change current refuge focus from waterfowl management to prairie restoration.
- At a minimum, work to maintain the current population levels of canvasback while trying to restore the population to historic levels. Maintain canvasback habitat with engineered structures to control water levels and by pumping groundwater into managed wetlands. Engage in predator control to compensate for the lowered reproductive success caused by wetland condition.

(4) Tree-line is moving upward in elevation and reducing the area of alpine habitat. Tree species generally associated with lower elevations seem to be expanding their range because of recent, mild climatic conditions. Further warming could allow some alpine habitat patches to disappear through forestation. Alpine habitats support numerous alpine dependent wildlife species like American pika, mountain goats, and ptarmigan.

- Treat the loss of alpine habitat as a loss of natural diversity. Engage in management activities, like mechanical removal, to reduce the recruitment of trees into alpine habitats. Maintain the current area and distribution of alpine habitats in order to sustain current population levels and meta-population structure of alpine dependent species.

- Treat the loss of alpine habitat as a natural process. Allow lower-elevation alpine habitats to convert to forest with the reduction of overall population levels of alpine dependent species. Use translocation of individuals to maintain gene flow between peaks that become isolated.

(5) The Hawaiian monk seal is an endangered species with a population of less than 1500 individuals that occur primarily in the Northwestern Hawaiian Islands. Most of these islands are low-lying and are therefore, vulnerable to sea level rise that is predicted to occur with future climate change. As much as 65 percent of island habitats are projected to be lost under a median scenario of climate change. Sandy beaches adjacent to shallow waters are important sites for parturition and nursing. Sea level rise will decrease the size of these beaches causing crowding and competition for suitable habitat. In addition, the crowding of monk seals on the remaining beaches has been suggested to facilitate shark predation on the pups. Loss of beach habitat and increased pup mortality increases the probability of a population decline and the global extinction of the species.

- Consider the reduction of beach habitat and the resulting changes to the monk seal population to be a natural process. Reduce the other stressors to monk seal populations like human disturbance. Focus efforts on facilitating natural shoreline movement and identifying and conserving lands that may provide beach habitat in the future. Allow the population to decline to levels that can be supported by the limited beach habitat even though the extinction risk to the species will be higher than under current conditions. Use a population viability analysis to identify the minimum population size needed to avoid extinction and use techniques like captive breeding if the population falls below this number.

- Consider the reduction of beach habitat and the resulting changes to the monk seal population to be an unacceptable risk to maintaining natural diversity. Work to maintain current population levels. Reduce other stressors to monk seal populations due to human disturbance and engage in efforts to reduce shark predation. If reducing other stressors does not fully compensate for the loss of beach habitat, use dredge soil to replenish beaches after erosion events and to build up areas subject to inundation.

(6) Climate change models linked to vegetation models predict that biomes will shift into a new spatial distribution in the future. If your refuge fell into an area expected to undergo a biome shift, species would likely colonize the refuge in the future given climate change and no management actions. Some species may also be extirpated from the refuge. If climate change occurred, which management response do you think would be the most appropriate as species colonized and/or became extirpated?

- Consider historic species assembles to represent the natural diversity of the refuge. Maintain historic species assembles. In other words, do not allow species to colonize or become extinct.
- Consider colonization to be a natural process that increases natural diversity. Allow new species to migrate into your refuge while engaging in management activities to maintain species that were historically present.
- Consider extirpation and colonization to be natural processes. Allow new species to migrate into your refuge and species historically present to become locally extinct through migration and/or competition with new species.

(7) Hotter, longer summer seasons have increased the frequency and duration of wildfires leading to concerns that the fire disturbance regime is outside the range of historic variability. Old-growth forest stands are becoming rare on the landscape and existing old growth stands may have an increased probability of experiencing a forest fire. The ecosystem in your refuge seems to be shifting from a forest matrix of various stand ages to a landscape dominated by early successional stands. Old-growth dependent species are shifting distribution into the remaining old-growth patches, but many patches are not large enough to sustain viable populations of these species. However, species dependent on early successional forest are increasing.

- Consider the new fire frequency associated with a warming climate to be outside of the natural fire regime. Use fire management techniques like suppression and prescribed burning to maintain historic variability. Protect remaining old-growth stands. Maintain the suite of old-growth dependent wildlife species that occurred with the natural fire regime on your refuge lands.
- Consider the fire frequency associated with a warming climate to be a new natural fire regime. Allow all naturally ignited fires to burn whenever possible. Ensure that the genetic diversity of species within old-growth stands is not lost through translocation of representative individuals to similar forest types in other areas when natural dispersal is not viable. Allow some forest-dependent wildlife species that cannot be sustained in small patches to be extirpated from the refuge.

Do you have any additional thoughts, opinions, or comments?

Please submit your questionnaire by pressing the "Submit by Email" button.

When I receive the data from your questionnaire, I will save the file without identifying your email address and delete your email.

May I contact you for a follow up interview?

Interviews will take about an hour and will provide an opportunity to engage in a more thorough discussion about the topic of climate change and your opinions about the opportunities and challenges, if any, that climate change will present to the System.

If you would like to be contacted, please email me (dawn.magness@uaf.edu) and give me a phone number or email address where you would like to be contacted.

Thank you for completing the questionnaire

Appendix E

Climate Change Scenarios Used in Questionnaire

Question 1: Should species expanding their historic range be treated as invasive?

Q1: Endangered Species Scenario

The northern spotted owl is a threatened species that is restricted to old-growth forests in the Pacific Northwest. Northern spotted owls are displaced from occupied territories when barred owls are present. Barred owls were historically restricted to eastern North America, but have extended their range westward across Canada to British Columbia. From British Columbia, the barred owl range continued to expand south into the Pacific Northwest and north to southeast Alaska. Among other factors, climate change may have facilitated the range expansion of barred owls. Future climatic change may cause barred owl populations to increase at the expense of the spotted owl population.

> **Anticipatory Strategy:** Barred owls should not be considered an invasive species in the historic range of northern spotted owl because barred owls are expanding their range without human assistance. Allow barred owl populations to increase as spotted owl populations decline. Focus effort of reducing other stressors to northern spotted owl populations like forest management practices that reduce old-growth habitat.
>
> **Reactionary Strategy:** Consider barred owl to be an invasive species within the historic range of northern spotted owls. Engage in efforts like trapping to control barred owl populations within the historic range of northern spotted owl.

Q1: Single-species Scenario

Red fox are moving northward into areas historically occupied by arctic fox due to a warming climate. Arctic fox are unable to expand their range northward because the Arctic Ocean is an obstacle. Arctic fox are competitively excluded from areas occupied by red fox, so the arctic fox population is declining.

> **Anticipatory Strategy:** Red fox should not be considered an invasive species within the range of arctic fox because red fox are moving without human assistance. Allow red fox populations to increase as arctic fox populations decline. Study the climatic limits of red fox distributions and, based on future scenarios of climate change, identify the local areas with the historic range of Arctic fox that will likely serve as refugia in the future.

Focus on efforts to conserve lands identified as likely arctic fox refugia.

Reactionary Strategy: Treat red fox as an invasive species within the historic range of arctic fox. Engage in efforts like trapping to control red fox populations within the historic range of arctic fox in order to maintain historic arctic fox population levels.

Q1: Ecosystem Scenario

Mountain pine beetles were historically distributed in lodgepole pine ecosystems of the western United States. Although lodgepole pines extend into Canada, mountain pine beetles have been limited from expanding northward by climate and limited from expanding eastward by the Great Plains. Recently, mild temperatures have allowed mountain pine beetles to expand northward into lodgepole pine and jack pine forests in British Columbia causing a beetle outbreak that is unprecedented in size and located in an area with no previously observed beetle activity. Large numbers of beetles have also been documented dispersing through low-elevation mountain passes and have established populations east of the Continental Divide where mountain pine beetles have never occurred. Mountain pine beetles have the potential to move across the contiguous boreal jack pine forests of eastern North America all the way to the loblolly forests of the southeastern United States. The ecological consequences of mountain pine beetle range expansion are currently unknown, but have the potential to be devastating.

Anticipatory Strategy: Mountain pine beetles should not be treated as an invasive species east of the Continental Divide because they are native and moving without human assistance. Allow mountain pine beetles to move into areas where they naturally colonize. Monitor the effects of mountain pine beetles on the ecosystems east of the Continental Divide. Identify isolated stands in the East that can serve as forest refugia given beetle outbreaks and focus efforts on conserving these stands.

Reactionary Strategy: Mountain pine beetles should be treated as an invasive species east of the Continental Divide because they were not historically present there. Monitor outbreaks that occur east of the Continental Divide and control the spread of these outbreaks with pesticides, biological control, and forestry practices.

Question 2: Is it acceptable to translocate species outside of their historic range?

Q2: Endangered Species Scenario

The Hawaiian monk seal is an endangered species with a population of less than 1500 individuals that occur primarily in the Northwestern Hawaiian Islands. Most of these islands are low-lying and are therefore, vulnerable to sea level rise that is predicted to occur with future climate change. As much as 65 percent of island habitats are projected to be lost under a median scenario of climate change. Sandy beaches adjacent to shallow waters are important sites for parturition and nursing. Sea level rise will decrease the size of these beaches causing crowding and competition for suitable habitat. In addition, the crowding of monk seals on the remaining beaches has been suggested to facilitate shark predation on the pups.

> **Anticipatory Strategy:** Identify habitats that could support monk seal populations in the future given climate change. Conduct translocations of animals to these locations even if they occur outside the historic range for Hawaiian monk seals. On beaches where seals have historically occurred, allow the population to decline to levels that can be supported by the limited beach habitat as sea levels rise.

> **Reactionary Strategy:** Focus efforts on protecting existing seal beaches from inundation and erosion with engineered structures. Use dredge spoil to replenish beaches after erosion events and to build up areas subject to inundation. Try to maintain historic population levels on beaches where seals currently occur by reducing other stressors to monk seal populations like disturbances from domestic animals and shark predation.

Q2: Single-species Scenario

Desert bighorn sheep are a subspecies of bighorn sheep. Hotter temperatures and a decrease in precipitation in SE California have reduced the forage available for desert bighorn sheep. Lack of forage has been a contributing factor in the extinction for 30 of the 80 known populations. Increased temperature and a lack of precipitation in the future will significantly increase the probability of more population extinctions.

> **Anticipatory Strategy:** Identify alternative habitats that could provide suitable forage for desert bighorn sheep in the future as climate condition change. Conduct translocations of animals to these locations even if they occur outside the historic range of desert bighorn sheep. In habitats where

bighorn sheep have historically occurred, allow population to decline to levels that can be supported by available forage given hotter, drier conditions.

Reactionary Strategy: Focus efforts on maintaining current population levels in habitat where sheep have historically occurred. Reduce other stressors on desert sheep populations like hunting pressure, predation rates, domestic sheep grazing, and other disturbance. Begin a feeding program to ensure adequate nutrition in years when forage is lacking.

Q2: Ecosystem Scenario
Predicted levels of sea level rise indicate complete inundation (within the next 50 years) of an island which includes several unique habitat types that support endemic species of amphibians, arthropods and plants.

Anticipatory Strategy: Allow island to be inundated. Conduct translocations of endemic species to other islands or mainland areas with similar habitat even though these areas are outside of the historic range for these species.

Reactionary Strategy: Construct levee, dyke, or other engineered structures to protect island.

Question 3: What temporal reference point should be used for restoration?
Q3: Endangered Species Scenario
The Hawaiian monk seal is an endangered species with a population of less than 1500 individuals that occur primarily in the Northwestern Hawaiian Islands. Most of these islands are low-lying and are therefore, vulnerable to sea level rise that is predicted to occur with future climate change. As much as 65 percent of island habitats are projected to be lost under a median scenario of climate change. Sandy beaches adjacent to shallow waters are important sites for parturition and nursing. Sea level rise will decrease the size of these beaches causing crowding and competition for suitable habitat. In addition, the crowding of monk seals on the remaining beaches has been suggested to facilitate shark predation on the pups. Loss of beach habitat and increased pup mortality increases the probability of a population decline and the global extinction of the species.

Anticipatory Strategy: Allow the population to shift to levels that can be supported by the limited beach habitat available in the future. Reduce other stressors to the monk seal population that occur due to human disturbance. Use a population viability analysis to identify the minimum population size needed to avoid extinction. If the limited beach habitat results in a population size below the population minimum, use techniques like captive breeding.

Reactionary Strategy: Work to maintain current population levels while trying to restore population numbers to historic levels. Reduce other stressors to monk seal populations due to human disturbance and engage in efforts to reduce shark predation. If reducing other stressors does not fully compensate for the loss of beach habitat, use dredge soil to replenish beaches after erosion events and to build up areas subject to inundation.

Q3: Single-species Scenario
The wetlands of the prairie pothole region provide important breeding habitat for canvasback ducks. Temperature and rainfall affect wetland condition. Wetland condition affects the size of the breeding population in a given area and the reproductive success of canvasback. Climate change projections predict that warming temperatures and changing precipitation patterns will result in fewer wetlands and greater annual variability in surface water. These changes are linked to lowered reproductive success due to factors like lower nesting success, smaller clutch sizes, and lower brood survival. Your refuge in the prairie pothole region has been subject to drought conditions for several years leading to a reduction in high quality wetland habitat and reduced canvasback numbers.

Anticipatory Strategy: Allow wetland conditions within your refuge to change with the changing climate. Allow the canvasback population within the refuge boundary to decline to levels that can be supported by wetland conditions in the future. Change current refuge focus from waterfowl management to prairie restoration.

Reactionary Strategy: At a minimum, work to maintain the current population levels of canvasback while trying to restore the population to historic levels. Maintain canvasback habitat with engineered structures to control water levels and by pumping groundwater into managed wetlands. Engage in predator control to compensate for the lowered reproductive success caused by wetland condition.

Q3: Ecosystem Scenario
Approximately one-third of coastal marshland has been lost since the 1930s on your refuge. Sea level rise inundates coastal marshlands and sea levels are

expected to continue to rise with climate change. Nutria, an exotic rodent, also contributes to the loss of coastal marshland through overgrazing. Nutria populations are limited by harsh winter conditions and may increase in numbers with a warming climate. The area of coastal marshland within your refuge is decreasing.

> **Anticipatory Strategy:** Allow the current area of coastal marshland within your refuge boundary to convert to deeper water habitat. Shift management focus on refuge from dabbling ducks to diving ducks. Engage in efforts to identify and conserve lands that will be coastal marshland in the future. Work to facilitate the movement of coastal marshland inland across refuge lands by raising roadbeds even if marshland in the future will occur outside of the refuge boundary.

> **Reactionary Strategy:** At a minimum, work to maintain the current area of coastal marshland habitat in your refuge boundaries while trying to restore coastal marshland to historic levels. Focus efforts on reducing nutria populations to minimize nutria contribution to marshland loss. Work to restore wetlands through reducing saltwater inundation with engineered structures, the beneficial use of dredge spoil, supplemental planting efforts, and prescribed fire.

Question 4: Is extirpation of a species/habitat from a local geographic area due to climate change natural when it exists elsewhere?

Q4: Endangered Species Scenario

Loggerhead sea turtles are an endangered species with major nesting grounds in the United States from North Carolina to southwest Florida and minor nesting grounds occurring westward to Texas and northward to Virginia. Globally, 3 populations of loggerhead turtles exist with some nesting activity on every continent. Climate change is expected to impact loggerhead sea turtle nesting habitat via rising sea levels due to factors like the thermal expansion of warming oceans and glacial melt. Erosion of nesting habitat will also be accelerated by increases in the frequency of storm events. Narrow, low-elevation beaches are the most susceptible to inundation. Beaches with shoreline development will also be vulnerable because erosion control structures limit shoreline movement. Nesting success will be lower on beaches subject to repeated, tidal inundation. The nesting habitat on your refuge is vulnerable to erosion and inundation.

> **Anticipatory Strategy:** Consider the loss of loggerhead sea turtle nesting habitat from sea level rise and changes to storm frequencies to be a

natural process. Allow nesting success to decline on your refuge because these beaches are susceptible to erosion and inundation. Focus on the global identification and conservation of beaches that are more likely to withstand erosion and inundation as sea levels rise and storm frequencies change locally. Reduce other stressors to loggerhead sea turtle populations like adult mortality related to commercial fisheries.

Reactionary Strategy: Consider the lowered nesting success rates of loggerhead sea turtles and the loss of nesting habitat on your refuge to be a threat to natural diversity. Monitor nesting sites and collect eggs for rearing when weather events threaten to inundate nests. Focus efforts on protecting existing shoreline within the refuge from erosion and inundation with engineered structures. Use dredge spoil to replenish eroded beaches.

Q4: Single-species Scenario
Red fox distributions are shifting northward into areas historically occupied by arctic fox due to trends of warming climate. Arctic fox are unable to expand their range northward because the Arctic Ocean is an obstacle. Arctic fox are competitively excluded from areas occupied by red fox, so the range of Arctic fox is constricting.

Anticipatory Strategy: Treat the range expansion of red fox and the range contraction of arctic fox as a natural process. Study the climatic limits of red fox distributions and, based on future scenarios of climate change, identify the local areas with the historic range of Arctic fox that will likely serve as refugia in the future. Focus on efforts to conserve lands identified as likely arctic fox refugia. Allow arctic fox populations to be extirpated from a large portion of their historic range, while the range of red fox expands.

Reactionary Strategy: Treat the range expansion of red fox as a threat to natural diversity because the arctic fox may be extirpated from a large portion of their historic range. Engage in controlling red fox populations within the historic range of arctic fox in order to maintain the historic ranges of both species.

Q4: Ecosystem Scenario
Tree-line is moving upward in elevation and reducing the area of alpine habitat. Tree species generally associated with lower elevations seem to be expanding their range because of recent, mild climatic conditions. Further warming could

allow some alpine habitat patches to disappear through forestation. Alpine habitats support numerous alpine dependent wildlife species like American pika, mountain goats, and ptarmigan.

> **Anticipatory Strategy:** Treat the loss of alpine habitat as a natural process. Allow lower-elevation alpine habitats to convert to forest with the reduction of overall population levels of alpine dependent species. Use translocation of individuals to maintain gene flow between peaks that become isolated.

> **Reactionary Strategy:** Treat the loss of alpine habitat as a loss of natural diversity. Engage in management activities, like mechanical removal, to reduce the recruitment of trees into alpine habitats. Maintain the current area and distribution of alpine habitats in order to sustain current population levels and meta-population structure of alpine dependent species.

<u>Question 5: is extinction of a species/habitat due to climate change natural?</u>

Q5: Endangered Species Scenario

The Hawaiian monk seal is an endangered species with a population of less than 1500 individuals that occur primarily in the Northwestern Hawaiian Islands. Most of these islands are low-lying and are therefore, vulnerable to sea level rise that is predicted to occur with future climate change. As much as 65 percent of island habitats are projected to be lost under a median scenario of climate change. Sandy beaches adjacent to shallow waters are important sites for parturition and nursing. Sea level rise will decrease the size of these beaches causing crowding and competition for suitable habitat. In addition, the crowding of monk seals on the remaining beaches has been suggested to facilitate shark predation on the pups. Loss of beach habitat and increased pup mortality increases the probability of a population decline and the global extinction of the species.

> **Anticipatory Strategy:** Consider the reduction of beach habitat and the resulting changes to the monk seal population to be a natural process. Reduce the other stressors to monk seal populations like human disturbance. Focus efforts on facilitating natural shoreline movement and identifying and conserving lands that may provide beach habitat in the future. Allow the population to decline to levels that can be supported by the limited beach habitat even though the extinction risk to the species will be higher than under current conditions. Use a population viability analysis

to identify the minimum population size needed to avoid extinction and use techniques like captive breeding if the population falls below this number.

Reactionary Strategy: Consider the reduction of beach habitat and the resulting changes to the monk seal population to be an unacceptable risk to maintaining natural diversity. Work to maintain current population levels. Reduce other stressors to monk seal populations due to human disturbance and engage in efforts to reduce shark predation. If reducing other stressors does not fully compensate for the loss of beach habitat, use dredge soil to replenish beaches after erosion events and to build up areas subject to inundation.

Q5: Single-species Scenario
Desert bighorn sheep are a subspecies of bighorn sheep. Hotter temperatures and a decrease in precipitation in SE California have reduced the forage available for desert bighorn sheep. Lack of forage has been a contributing factor in the extinction for 30 of the 80 known populations. Increased temperature and a lack of precipitation in the future will significantly increase the probability of global extinction of this species.

Anticipatory Strategy: Consider the reduction in forage due to climatic changes to be a natural process. Reduce other stressors on desert sheep populations like hunting pressure, predation rates, domestic sheep grazing, and other disturbance. Allow population levels to decline to levels that can be supported by available forage, even though the extinction risk to the subspecies will be higher than under current conditions. Use a population viability analysis to identify the minimum population size needed to avoid extinction and use techniques like captive breeding if the population falls below this number.

Reactionary Strategy: Consider the reduction of forage due to climatic changes to be an unacceptable risk to maintaining natural diversity. Focus efforts on maintaining current population levels. Begin a feeding program to ensure adequate nutrition in years when forage is lacking. Research plant species that could provide forage for desert bighorn sheep and survive the hotter dryer climatic conditions. Begin a program to plant species that are identified by research program.

Q5: Ecosystem Scenario
Predicted levels of sea level rise indicate complete inundation (within the next 50

years) of an island which includes several unique habitat types that support endemic species of amphibians, arthropods and plants.

Anticipatory Strategy: Consider the loss of the island and the species endemic to the islands to be a natural process. Allow island to be inundated. Collect endemic animal species to maintain in zoo collections and endemic plants for seed banks.

Reactionary Strategy: Consider the loss of the island to be an unacceptable loss of natural diversity and unique natural habitat. Construct levee, dyke, or other engineered structures to protect island.

Question 6: What should be considered natural diversity given ciimate change?

Q6: Endangered Species Scenario

Climate change models linked to vegetation models predict that biomes will shift into a new spatial distribution in the future. If your refuge fell into an area expected to undergo a biome shift, endangered species could colonize the refuge in the future given climate change and no management actions. In addition, it would also be possible for endangered species to be extirpated from the refuge. If climate change occurred, which management response do you think would be the most appropriate if an endangered species colonized and/or became extirpated?

Anticipatory Strategy: Consider extirpation and colonization to be natural processes. Allow new endangered species to migrate into your refuge and endangered species historically present to become locally extinct through migration and/or competition with new species.

Both: Consider colonization to be a natural process that increases natural diversity. Allow new endangered species to migrate into your refuge while engaging in management activities to maintain endangered species that were historically present.

Reactionary Strategy: Consider historic species assembles to represent the natural diversity of the refuge. Maintain endangered species assemblages that were historically present. In other words, do not allow endangered species to colonize or become extirpated.

Q6: Single-species Scenario
Climate change models linked to vegetation models predict that biomes will shift into a new spatial distribution in the future. If your refuge fell into an area expected to undergo a biome shift, species would likely colonize the refuge in the future given climate change and no management actions. Some species may also be extirpated from the refuge. If climate change occurred, which management response do you think would be the most appropriate as species colonized and/or became extirpated?

Anticipatory Strategy: Consider extirpation and colonization to be natural processes. Allow new species to migrate into your refuge and species historically present to become locally extinct through migration and/or competition with new species.

Both: Consider colonization to be a natural process that increases natural diversity. Allow new species to migrate into your refuge while engaging in management activities to maintain species that were historically present.

Reactionary Strategy: Consider historic species assembles to represent the natural diversity of the refuge. Maintain historic species assembles. In other words, do not allow species to colonize or become extinct.

Q6: Ecosystem Scenario
Climate change models linked to vegetation models predict that biomes will shift into a new spatial distribution in the future. If your refuge fell into an area expected to undergo a biome shift, the ecosystem characteristics of the refuge would likely change in the future given climate change and no management actions. If climate change occurred, which management response do you think would be the most appropriate as ecosystem characteristics changed?

Anticipatory Strategy: Consider the ecosystem changes that occur with species extirpation and colonization to be a natural process. Allow new species to migrate into your refuge and species historically present to become locally extinct through migration and/or competition with new species.

Both: Consider colonization to be a natural process that increases natural diversity. Allow new species to migrate into your refuge while engaging in management activities to maintain species that were historically present.

Reactionary Strategy: Consider historic species assembles and ecosystem characteristics to represent the natural diversity of the refuge. Maintain historic species assembles and ecosystem characteristics. In other words, do not allow species to colonize or become extinct.

Question 7: What should be considered natural disturbance regime given climate change?

Q7: Endangered Species Scenario

The northern spotted owl is a threatened species that is restricted to old-growth forests in the Pacific Northwest. Warmer, drier summers produce more frequent and more extensive fires in forest ecosystems leading to concerns that the fire regime will shift outside the range of natural variability with future climate change. This change to the natural fire regime will reduce the extent and connectivity of late-successional stands and therefore, reduce the amount of habitat suitable for northern spotted owls.

Anticipatory Strategy: Consider the fire regime associated with a warming climate to be a new natural fire regime. Allow all naturally ignited fires to burn whenever possible. Allow northern spotted owl habitat to be reduced and owl populations to shift to levels that can be supported given the new fire regime.

Reactionary Strategy: Consider the new fire frequency associated with a warming climate to be outside of the natural fire regime. Use fire management techniques like suppression and prescribed burning to maintain historic variability. Work to maintain a fire regime that will maintain current northern spotted owl habitat and support the historic owl population sizes.

Q7: Single-species Scenario

Brown creeper is a songbird associated with old-growth forests. In your area, warmer, drier summers have produced more frequent and extensive fires in forest ecosystems leading to concerns that the fire regime will shift outside the range of natural variability with future climate change. This change to the natural fire regime will reduce the extent of old-growth stands and therefore, reduce the amount of high quality breeding habitat for brown creepers.

Anticipatory Strategy: Consider the fire regime associated with a warming climate to be a new natural fire regime. Allow all naturally ignited fires to burn whenever possible. Allow brown creeper habitat to be reduced and brown creeper breeding populations in your refuge to shift to levels that can be supported given the new fire regime.

Reactionary Strategy: Consider the new fire frequency associated with a warming climate to be outside of the natural fire regime. Use fire management techniques like suppression and prescribed burning to maintain historic variability. Work to maintain a fire regime that will maintain current brown creeper breeding habitat and population sizes on your refuge.

Q7: Ecosystem Scenario
Hotter, longer summer seasons have increased the frequency and duration of wildfires leading to concerns that the fire disturbance regime is outside the range of historic variability. Old-growth forest stands are becoming rare on the landscape and existing old growth stands may have an increased probability of experiencing a forest fire. The ecosystem in your refuge seems to be shifting from a forest matrix of various stand ages to a landscape dominated by early successional stands. Old-growth dependent species are shifting distribution into the remaining old-growth patches, but many patches are not large enough to sustain viable populations of these species. However, species dependent on early successional forest are increasing.

Anticipatory Strategy: Consider the fire frequency associated with a warming climate to be a new natural fire regime. Allow all naturally ignited fires to burn whenever possible. Ensure that the genetic diversity of species within old-growth stands is not lost through translocation of representative individuals to similar forest types in other areas when natural dispersal is not viable. Allow some forest-dependent wildlife species that cannot be sustained in small patches to be extirpated from the refuge.

Reactionary Strategy: Consider the new fire frequency associated with a warming climate to be outside of the natural fire regime. Use fire management techniques like suppression and prescribed burning to maintain historic variability. Protect remaining old-growth stands. Maintain the suite of old-growth dependent wildlife species that occurred with the natural fire regime on your refuge lands.

Appendix F

Raw Results from Questionnaire

Table F-1. Establishment Purpose of Refuge. Questionnaire results for question 2, "What category best summarizes the primary establishment purpose of your refuge(s)?" Responses were summarized for individuals and by their refuge or refuge complex.

Purpose	Individual Response n = 202	Refuge & Complex n = 149
Conservation of migratory birds	58%	58%
Conservation of endangered and/or threatened species	7%	9%
Development and conservation of fish and/or wildlife resources	6%	5%
Conservation of fish and wildlife population and habitats in their natural diversity	26%	23%
I don't know	<1%	<1%
Other (see bullets below)	5%	3%

- We are a complex of 7 refuges with different establishing legislations
- Conservation of migratory species, coral reefs, E & T species, pelagic ecosystems and deep reefs
- Tallgrass prairie and savanna ecological restoration
- Provide winter range for elk and other big game animals
- Wetlands
- Conservation of Kodiak Brown Bear and other wildlife and fish populations and their habitat.
- Mitigation for central and south Florida flood control district under the migratory bird treaty act
- Preservation of unique wildlife, wilderness and recreation values

Table F-2. Respondents Working for Refuges and Complexes. Questionnaire results for question 3, "Is your refuge part of a complex?" Results summarized for individual respondents and for respondents that were compiled by the refuge or complex where they work.

Response	Individual Response n = 200	Refuge & Complex n = 149	Refuges Only n=101	Complexes Only n=48
Yes	68%	70%	59%	87%
No	34%	30%	39%	12%
I don't know	1%	<1%	1%	0%

Table F-3. Employment Series of Respondents. Questionnaire results for question 4, "What is the job series of your current position?" When compiled, 51% are managers and 49% are biologists. Series identify numerically referenced government job titles.

Series	Individual Responses n=201
485	50%
401	6%
404	1%
408	1%
486	37%
I don't know	<1%
Other	3%

Table F-4. Time at Refuge. Questionnaire results for question 5, "How long have you worked at this refuge?"

Time	Managers n=104	Biologists N=96
< 1 year	9%	6%
1-5 years	27%	16%
5-10 years	39%	39%
10-20 years	16%	31%
>20 years	8%	9%

Table F-5. Time in Refuge System. Questionnaire results for question 6, "How long have you worked in the National Wildlife refuge System?"

Time	Managers n=104	Biologists N=97
< 1 year	0%	1%
1-5 years	2%	8%
5-10 years	16%	35%
10-20 years	39%	35%
>20 years	42%	21%

Table F-6. Service in Other Regions. Questionnaire results for question 7, "Have you worked on other Regions as a Service employee?"

Response	Managers n=104	Biologists N=96
Yes	63%	27%
No	38%	73%

Table F-7. Number of Biologists. Questionnaire results for question 8, "How many permanent biologists or biological technicians are currently employed at your refuge?" Results were based on answers from each refuge or complex.

Number	Refuge & Complex n=149	Refuges n=101	Complexes n=48
0	13%	13%	16%
1	48%	52%	10%
2	13%	13%	18%
3	11%	8%	39%
4	7%	5%	2%
5	3%	3%	2%
6	0%	0%	0%
>6	5%	6%	2%

Table F-8. Refuges with Completed Comprehensive Conservation Plan. Questionnaire results for question 10, "Has your refuge or complex done a Comprehensive Conservation Plan (CCP)?" Respondents' answers were compiled by the refuge or complex where they work.

Response	Refuge & Complex n=146
Yes	52%
No	10%
In CCP process	38%

Table F-9. Climate Change Included in Comprehensive Conservation Plan (CCP) Generally. Questionnaire results for question 11, "Was climate change mentioned generally in the CCP?" Respondents' answers were compiled by the refuge or complex where they work. Only refuges or complexes with completed or started CCPs were included.

Response	Refuge & Complex with CCP Complete or CCP in Process n=133
Yes	36%
No	40%
Have not completed draft	22%
I don't know	2%

Table F-10. Climate Change Included as Comprehensive Conservation Plan (CCP) Issue. Questionnaire results for question 12, "Was climate change identified as an issue during scoping for the CCP?" Respondents' answers were compiled by the refuge or complex where they work. Only refuges or complexes with completed or started CCPs were included.

Response	Refuge & Complex with CCP Complete or CCP in Process n=133
Yes	19%
No	61%
Have not completed scoping	9%
I don't know	11%

Table F-11. Climate Change in Comprehensive Conservation Plan (CCP) Vision Statement. Questionnaire results for question 13, "Did the vision statement and/or goals in the CCP deal specifically with climate change mitigation, climate change education, or an impact of climate change?" Respondents' answers were compiled by the refuge or complex where they work. Only refuges or complexes with completed or started CCPs were included.

Response	Refuge & Complex with CCP Complete or CCP in Process n=131
Yes	8%
No	76%
Have not completed goals	16%
I don't know	<1%

Table F-12. Climate Change Included in Comprehensive Conservation Plan (CCP) Alternative. Questionnaire results for question 14, "Were any alternatives in the CCP formulated around climate change impacts?" Respondents' answers were compiled by the refuge or complex where they work. Only refuges or complexes with completed or started CCPs were included.

Response	**Refuge & Complex with CCP Complete or CCP in Process n=132**
Yes	4%
No	76%
Have not completed alternatives	20%
I don't know	<1%

Table F-13. Management Documents that Include Climate Change. Questionnaire results for question 15, "Is climate change included in other management documents for you refuge such as fire management plans or habitat management plans?" Respondents' answers were compiled by the refuge or complex where they work.

Response	**Refuge & Complex n=132**
Yes (see list of documents on Page 202)	13%
No	84%
I don't know	3%

List of Management Documents that Included Climate Change

- Draft EIS for proposed land exchange; listed in cumulative impacts section of report. I don't know if it is listed in the Fire management Plan; and it will be discussed during upcoming biological review and CCP revision.
- Draft Biological Review
- Other plans will be revised with CCP as step-down plans
- Biological Program Review
- Undergoing revision: Fire Management Plan, Habitat Management Plan, Biological Inventory and Monitoring Plan
- HMP
- We are in process of writing step down plans for Fire Management and Habitat Management Plans
- Arctic FMP
- Seabird Management Plan
- fire management, caribou management (interagency 7 stakeholder - cooperative plan 2003)
- plans are being written currently or will be stepdown plans to CCP
- M&I Plan, Fire Management Plan
- Fire Mgmt Plan
- Fire Management Plan, Habitat Management Plan(in progress)
- habitat management plan (in preparation)
- Goals and Objectives - probably in Fire Management Plan
- Habitat Management Plan
- HMP and Draft CCP
- Fire Management Plan
- It is mentioned in a current EIS for a land exchange.
- Habitat Management Plan
- Fire Management Plan
- Fire management plan

Table F-14. Climate Change Included in Management Plans Generally. Questionnaire results for question 16, "In the management document(s) that included climate change, was climate change mentioned generally?" Respondents' answers were compiled by refuge or complex where they work.

Response	Refuge & Complex that Included Climate Change in Management Documents n=19
Yes	89%
No	0%
Yes in some, but not all	11%
I don't know	0%

Table F-15. Climate Change Results in Management Plan Response. Questionnaire results for question 17, "In the management document(s) that included climate change, does an impact of climate change result in a management response?" Respondents' answers were compiled by the refuge or complex where they work.

Response	Refuge & Complex that Included Climate Change in Management Documents n=18
Yes	39%
No	39%
Yes in some, but not all	22%
I don't know	0%

Table F-16. Respondents Who Think Climate Change is Impacting Refuge. Questionnaire results for question 18, "Regardless of how planning documents refer or don't refer to climate change, do you personally think that climate change is impacting resources on your refuge?" Results compiled for all individuals, managers only, biologists only, and by the refuge or complex.

Response	Individual Responses n=203	Managers n=104	Biologists n=97	Refuge & Complex n=149
Yes	76%	74%	78%	79%
No	8%	8%	8%	7%
I don't know	16%	18%	13%	13%

Table F-17. Climate Change Impacts on Refuges. Questionnaire results for question 19, "What climate change impacts do you think are currently occurring on you refuge?"

Impact	Individual Respondents that Believe Impact is Occurring n=203	Managers that Believe Impact is Occurring n=104	Biologists that Believe Impact is Occurring n=97	Refuge & Complex with Respondent that Believes Impact is Occurring n=129
Changes to phenology; changes in timing of flowering, breeding, or migration	54%	51%	57%	69%
Changes to local weather patterns including extreme weather events	58%	58%	57%	73%
Changing demographics of species of concern	19%	15%	23%	26%
Changes in erosion rates	16%	11%	21%	19%
Changes in frequency or duration of disturbances like fire	22%	18%	26%	25%
Wetland drying	26%	25%	25%	30%
Desertification	<1%	0%	1%	2%
Increases in exotic, invasive, or injurious species	40%	42%	38%	52%
Hydrological change including changes in water volume and timing of hydrological events	54%	57%	52%	66%
Shifts in species distributions	37%	36%	40%	49%
Saltwater inundations or intrusion (sea level rise)	17%	18%	15%	19%
Habitat changes like rising treeline or the decline of historically dominant tree species	20%	18%	21%	23%
Other(s) (see list on Page 206)	8%	5%	13%	12%

<u>List of Other Climate Change Impacts Respondents have Observed</u>

- Perhaps changes in the structure (thickness) of river ice (due to warming winter temperatures may prevent thick ice sheets from forming with a potential impact on high water events (decrease in river ice jamming spring flood events followed by decrease in lake/slough/creek recharge events, and/or decreased ice scouring in early successional shrub communities (less disturbance) with a potential impact on moose forage..
- Potential changes in salmon resources
- Many changes I perceive are difficult to definitively pin to global climate change, but weather patterns and subtle changes in bird migration and other issues are suspect.
- Loss of subterranean ice formations which are critical to maintenance of cold air slopes in the Driftless Area. Cold air slopes support endangered species which face extinction if temperatures continue to rise on slopes as a result of loss of ice formations
- Invasives on the move up UMR corridor and tributaries
- All of these factors have changed dramatically as a result of climate change just since the Last Glacial Maximum. Each continues to change, although some at rates not meaningful to management.
- I believe we are on the cusp of seeing such changes in some native plant communities but these are long-lived, slow response species. There are also changes in invasive species demographics but I do not know that they are climate change issues.
- Coral bleaching, inundation of low-lying islets, loss of habitat for migratory birds, sea turtles, and an endangered seal species
- Change in the wintering areas of Central America and Southern Mexico
- Increase in frequencies and intensities of hurricanes
- Permafrost melting,
- Modifications of marine food webs
- increased sedimentation due to erosion and thaw slump events - potential impact to spawning areas
- Warming conditions beneficial to some species (ex. lake spawning/rearing sockeye salmon production & abundance). May be detrimental to cold water species (Arctic char), but we have no data available at this time to determine what actual effects are occurring.
- I don't see any of these as stand alone results of CC; other factors play into the degree of change
- Estuarine fish species replacing freshwater species that have historically inhabited the refuge.
- Increase in invasive plants just outside, but not within, refuge that may move onto refuge
- Earlier drying of soils causing lower moisture content late in the growing season.

Table F-18. Ciimate Change impacts Adequately Addressed. Questionnalre results for question 20, "In your opinion, were ciimate change impacts you identified as important adequately addressed in your refuge's CCP?" Only respondents that believe climate change is impacting their refuge answered question. Responses compiled for all individuals, managers only, biologist only, and by refuge or complex.

Response	Managers n=75	Biologists n=73	Refuge & Complex n=117
CCP not completed	44%	32%	38%
Yes	9%	8%	8%
No	43%	56%	50%
I don't know	4%	4%	3%

Table F-19. Climate Change Impact Documentation. Questionnaire results for question 21, "How have climate change impacts been documented on your refuge?" Only respondents that believe climate change is impacting their refuge answered question. Respondents' answers were compiled by the refuge or complex where they work.

Impact	Refuge & Complex n=118
Impacts have not been documented	44%
Anecdotal observations	67%
Unpublished refuge data	30%
Published studies or theses/dissertations on refuge lands	17%
Scientific literature on similar resources, but studied elsewhere	17%
Other(s) (see bullets below)	1%

- Weather anomalies have caused severe localized damage and disruption on and near refuge
- R3 has been studying CC impacts on Waterfowl nesting, projections of sea rise along the Miss River
- There have been >20 contributions to the technical literature on climate change studies from this refuge .
- coral bleaching at Palmyra Atoll NWR between 1987-1998
- surveys, inventories, and population trends
- also ongoing long term ecological research - more publications will be forthcoming
- Publications on quantitative global warming effects from professor from Bozeman who received Nobel Prize
- Our station is an official National Weather Service weather collection station
- Traditional knowledge
- Presentations in communities and professional meetings; study soon to be published

Table F-20. Need National Guidance. Questionnaire results for question 22, "In your opinion, does your refuge need Regional or National guidance about if and how climate change impacts should be managed?" Responses compiled for managers and biologists

Response	Managers n=102	Biologists n=96
Yes	60%	62%
No	23%	14%
I don't know	18%	25%

Table F-21. Frequency of Influential Landscape Drivers. Questionnaire results for question 23, "Please order the following 5 general drivers of landscape change, occurring on your refuge or in surrounding lands, from the most influential on your refuge (1) to the least influential (5)." n = 203.

Driver of Change	1	2	3	4	5
Landscape change and land-use conversion including, but not limited to urbanization	46%	25%	11%	9%	9%
Climate change	13%	12%	27%	22%	25%
Increasing influence of invasive, exotic, or injurious species	32%	32%	16%	11%	9%
Over-exploitation of resources including hunting, recreation demands, or extractive resource use	7%	14%	19%	22%	36%
Pollution including contaminants	2%	15%	28%	35%	20%

Table F-22. Average Ranking of Influential Landscape Drivers. Questionnaire results for question 23, "Please order the following 5 general drivers of landscape change, occurring on your refuge or in surrounding lands, from the most influential on your refuge (1) to the least influential (5)." The rankings were averaged for each driver for managers only, biologists only and by refuge or complex.

Driver of Change	Average Rank By Managers n=102	Average Rank By Biologists n=96	Average Rank Refuge & Complex n=202
Landscape change and land-use conversion including, but not limited to urbanization	1.8	2.3	2.1
Climate change	3.5	3.3	3.4
Increasing influence of invasive, exotic, or injurious species	2.3	2.3	2.3
Over-exploitation of resources including hunting, recreation demands, or extractive resource use	3.8	3.5	3.7
Pollution including contaminants	3.4	3.6	3.6

Table F-23. Climate Change as Natural or Anthropogenic. Questionnaire results for question 24, "In your opinion, when managing the impacts of climate change, should climate change be treated primarily as a natural process or as an anthropogenic process?"

Response	Managers n=104	Biologists n=96
Natural	18%	8%
Anthropogenic	41%	46%
Not relevant for management	29%	30%
I don't know	12%	16%

Table F-24. Frequency of Anticipatory Response for Scenario Questions. Percentage of respondents who chose the anticipatory response, number of respondents, and scenario target for each of the 7 scenario questions. The anticipatory response managed toward future conditions. For question 6, respondents had 3 choices: anticipatory, reactionary, or a blended strategy. The frequency of the blended strategy is in parentheses.

Question for Scenario	Ecosystem	Single Species	T & E Species	Aii
Q1: Range Expansions as Invasive Species	49% of 74 respondents with beetle kill as target	74% of 53 respondents with foxes as target	80% of 74 respondents with owls as target	67% of 201 respondents across targets
Q2: Translocation	84% of 68 respondents with an island target	77% of 71 respondents with sheep as target	78% of 52 respondents with seals as target	81% of 191 respondents across targets
Q3: Restoration Reference Point	64% of 53 respondents with marsh target	63% of 75 respondents with ducks as target	59% of 74 respondents with seals as target	62% of 202 respondents across targets
Q4: Local Extirpation	61% of 74 respondents with alpine target	68% of 74 respondents with foxes as target	58% of 53 respondents with seals as target	63% of 201 respondents across targets
Q5: Increased Extinction Risk	72% of 72 respondents with island target	89% of 53 respondents with sheep as target	57% of 75 respondents with seals as target	71% of 200 respondents across targets
Q6: Natural Diversity	29% of 52 respondents chose colonization and extirpation (62% chose colonization, not extirpation)	25% of 72 respondents chose colonization and extirpation (71% chose colonization, not extirpation)	32% of 74 respondents chose colonization and extirpation (65% chose colonization, not extirpation)	29% of 198 respondents chose colonization and extirpation (66% chose colonization, not extirpation)
Q7: Disturbance Regimes	36% of 73 respondents with old-growth target	44% of 73 respondents with songbird as target	38% of 52 respondents with owls as target	39% of 198 respondents across targets

Table F-25. Anticipatory Response Frequency for Scenario Questions by Managers. Percentage of managers who chose the anticipatory response, geared toward probable future conditions, for each of the 7 scenario questions. For question 6, managers had three choices: anticipatory, reactionary, or a blended strategy. The frequency of the blended strategy is in parentheses.

Question for Scenario	Ecosystem	Single Species	T & E Species	All Targets
Q1: Range Expansions as Invasive Species	45%	78%	75%	66%
Q2: Translocations	82%	69%	82%	77%
Q3: Restoration Reference Point	68%	57%	58%	60%
Q4: Local Extirpation	69%	66%	64%	67%
Q5: Increased Extinction Risk	74%	89%	57%	72%
Q6: Natural Diversity	33% (63%)	23% (71%)	34% (61%)	30% (65%)
Q7: Disturbance Regimes	27%	46%	40%	37%

Table F-26. Anticipatory Response Frequency for Scenario Questions by Biologists. Percentage of biologist who chose the anticipatory response, geared toward probable future conditions, for each of the 7 scenario questions. For question 6, biologists had three choices: anticipatory, reactionary, or a blended strategy. The frequency of the blended strategy is in parentheses.

Question for Scenario	Ecosystem	Single Species	T & E Species	All Targets
Q1: Range Expansions as Invasive Species	53%	71%	83%	68%
Q2: Translocations	88%	86%	83%	86%
Q3: Restoration Reference Point	63%	70%	61%	65%
Q4: Local Extirpation	54%	69%	54%	60%
Q5: Increased Extinction Risk	71%	88%	57%	69%
Q6: Natural Diversity	25% (63%)	27% (69%)	31% (69%)	28% (68%)
Q7: Disturbance Regimes	46%	47%	30%	42%

Written Comments

- A11: The options / answers in the above questions reflect the current management thinking that we on refuges can only manage the lands within our jurisdiction. I believe there is a third option, one that means looking beyond our boundaries. Yes, climate change in a natural process (caused or accelerated by humans) and changes in the landscape and populations are going to occur. We can adapt to the changes at our stations, which may mean that the barred owl will encroach on spotted owl habitat. But there is somewhere else north of spotted owl habitat, that may be becoming better spotted owl habitat. We can focus our concern and management on maintaining corridors for movement of plant and animal species to migrate latitudinally, which may mean into lands that we currently do not have management jurisdiction over. Forming partnerships with other land owners, or looking ahead to identify tracts of land that will become important in maintaining species diversity. Our management focus also needs to change from artificially maintaining populations to managing ourselves and operations to reduce the contribution we make to climate change. What are we doing to reduce our carbon footprint? What are we doing to maintain open migratory corridors and natural processes? This is what I see as anthropogenic management--managing for the future.
- A12: Although I indicated earlier in the survey that I think climate change results from anthropogenic sources, I responded to the above essays in ways indicating that climate change is a natural change (i.e. agreeing that changes should be allowed to take their natural course). I responded this way because it seems very unrealistic to expect that we can change things without huge financial costs or impracticalities (i.e. suppressing fires, saving seals by dredging up more substrate to recreate beach habitat, preventing switch of dominant forest types from conifer to deciduous, etc.). Some of the solutions listed do not seem very practical to manage. Also, we were not given choices/options to prevent more habitat degradation, for example, in the Prairie Pothole Region, returning agricultural fields to their former wetlands, closing beaches during monk seal pup rearing, slowing logging in old growth forests...is it because these solutions are insurmountable and unacceptable as well?
- A15: Some of the proposed responses to scenarios have internal conflicts/contradictions to my "philosophy", as you put it, towards conservation practices. I'm sure you intended to limit the number of potential responses in order to force us to make a decision given only the limited choices you provided. But this is bound to bias any interpretation you may make. I'm not trying to be difficult but, this questionnaire is way too simplistic to even begin chipping away at FWS employees' opinions and ideas regarding conservation practices, options, and approaches. The questions may even tend towards "leading". Choice of response in some cases was too limited - in some cases no proposed management actions you listed were satisfactory. In some cases all management responses you listed were not satisfactory, therefore I did not make a selection. In other cases an offered response was only minimally satisfactory. It almost

makes me suspicious regarding motives (maybe I'm just being paranoid)?). Anyway, I'd like to see how these results are used and I certainly hope that we get an opportunity for more detailed explanations of our "philosophy".

- A18: I believe that if climate change is in fact caused or exacerbated by anthropogenic factors, then we should be using our resources to stop the source of the problem. It makes far more sense to stop contributing to climate change than to fight it after it has altered habitats, shifted species ranges and caused extirpation and potential extinction.
- A19: only that this issue seems so overwhelmingly large and we are already so underfunded and understaffed that I felt compelled to select the answers that seem to be the most realistic; i.e. we won't have the staff, funding, support to try and "save" endangered sps habitats or even the sps themselves.
- A23: do not believe that there are always only two or three options available to consider in making choices. We must be careful to consider creative options that are perhaps a blend of the options you offer on this questionnaire, or that are totally different. I think we need to be especially concerned about using a broad representation of gene pools when moving non-motile species from place to place, or in ecological restoration applications. Genetic diversity may be key in survival of some semblance of ecosystems. Corridors for plants and invertebrates have not been a traditional focus of the FWS, but we need to begin planning for such corridors. They are intrinsically important and are important for wildlife dependant on such areas. We will need to begin to think much more creatively and not rely as much on purely mechanistic answers.
- A25: My general attitude is not to fight the climate change, unless it involves saving an endangered species. Some species may be able to shift and occupy newly created or habitats, while others are going to take a hit. We should take them on a case-by-case basis, and that requires a lot of study. The extent of the efforts we are willing to make should take everything into account.
- A29: Questions 11 through 15 were answered in regards to Upper Miss Refuge. The CCP for Driftless Area NWR did recognize climate change as the most significant threat to talus algific slopes.
- A32: no easy answer, most solutions beyond letting populations/habitat stabilize on their own as climate conditions dictate are going to be very expensive. Wish I had the answer.
- A34: 7 questions above were practically unanswerable. It would all depend on an analysis of effectiveness of management to maintain "former historic conditions". Given the scale of the expected changes and very limited resources, the long-term solution of protecting habitats elsewhere that will support the former complex of species is probably most practical.
- A35: In all the stories above, there is no good answer and it is not that black and white...most of the time I wanted an answer that was somewhere in between the two.
- A36: Dawn: The 7 case studies you posed are quite provocative. They are really excellent tools for framing how to think about the impact of global climate change

on a refuge. We have completed 3 CCPs (no discussion of GCC) but are working on 5 more which will look at it. These questions will help us.

- A39: Job one for all people is to conserve energy, reduce consumption, reverse fossil fuel combustion and CO2 trends - a few more degrees finishes polar and glacial melting, releases stored methane, acidifies the ocean, floods the coastal beaches, estuaries , reefs, lowlands, while burning off the tropics, tundra, montane forests and alpine meadows. The management activities envisioned in these scenarios assume that everything else goes on indefinitely, business as usual. The truth is, we're aboard an industrial titanic, headed into the fog at ramming speed, while the crew and passengers demolish the deck chairs and life boats to continue stoking the boiler. The captain and the first mate are crazed by greed and crooked to the core., not in the least concerned about how many go down with the ship, much less all those polar bears and penguins. We can apply management dressings in the triage ward and try to ignore reality, or we can try to join together to forcefully and immediately steer our vessel in a different direction. toward a safer, cooler harbor. We're in survival mode now, and everything and everybody depends on our making the right decision.
- A41: These are tough choices! In the end, it will be the charismatic species that we go to great lengths to preserve, while the not-so-charismatic will be allowed to "shift" until they are gone.
- A42: Scenarios may be good examples but answer options are the extremes; management will likely fall in between those options.
- A44: Some very tough decisions, and the context was important in deciding which way to go.
- A47 (Labeled b): Climate change puts us in a tough spot, as stated in your stories. Endemic and threatened species need to saved on individual refuges, where possible. Long-distance and large-scale translocations appear to be insignificant to sustaining species, especially where they compete with other species at the receiving end. I would suggest that refuges become examples of how to reduce consumption by "going green" with construction and by sequestering carbon via habitat management. The later option may lead to species extirpation at local areas, however entire species extinction should not be caused here. Refuges need to act more quickly than being instructed to do so at this time. Farming practices and production of biofuels in our watersheds will reduce water available to the refuge by excessive water use, particularly corn-based biofuels; soil erosion will increase input of sediments , nutrients, and pesticides.
- A48: The impacts associated with the lack of human population growth controls (IE urbanization, reduction in land mass kept in a natural state, industry/vehicle emmissions etc.) when combined with "human " needs will continue to put the squeeze on natural communities. Trying to now factor in climate changes associated with the "human" impacts will be challenging and reports give us 10 years to make critical decisions. Keep in mind that a large % of the lands owned/administered by the USFWS is low elevation and directly affected by

hydrological events. Please note that the barred owl issue firstly, is a result of both male and female taking over home ranges and exploitation of old growth timber, that once harvested will not be allowed to regenerate to the old growth stage again. I was a biologist with the BLM in Oregon from 91 - 98. Oh the memories!! Changes to Forest Management practices, critical decision post wildfires, and silviculture practices that support natural regeneration within harvested units as well could make a huge impact to NSO's. Awesome ? Climate Change is it natural or anthropogenic

- A49: I managed the Hawaiian Is. NWR from 1993-1997. The best answer is a hybrid between the two choices. Based on you guidance it is unreasonable to assume or hope for the money to maintain islands by any construction/engineering solution. Closure of all or nearly all remote island habitats is in practice. Limited removal of hazardous debris and shark control are possible and are also underway. More effort to establish use of main HI islands as haul-outs and breeding sites will be challenging, but are reasonable to pursue. Finally, although the seal is very high profile, there are many other endemic species in the archipelago at great risk due to climate change, and all actions need to take this into account and not be made solely to enhance the survival chances of the seal without regard to undesirable impacts.
- A50: I do not support an all or non approach to this question. I recommend using the CCP or NEPA process to address these types of issues and find a preferred alternative that reflects the regional interests based on the specific landscape, species, expected rate of change, cost, and cultural values of all of this to all the potentially affected interests. I am comfortable in different refuges ending up at different points of the "let nature take its course" v maximum effort to maintain historic conditions. We need guidelines not hard and fast rules.
- A51: Climate change has been a continuous part of Earth's history. Climate has been particularly variable during the Pleistocene and Holocene, and is best understood for these recent times. All of my answers are provided in this context. I suspect that the focus of your study is the recent interest in human effects on climate change, but you don't make that clear in this questionaire. Further, I suspect your results would be more interesting and relevant if you more clearly addressed this.
- A52: Global climate change is occurring, and the extent and cause (i.e., natural cycle or anthropocentric) is under much debate in the scientific and political arenas. The NWRS will be affected by global climate change; however, it is my firm belief that global climate change is not the most serious issue facing the NWRS or global wildlife resources and habitats. Human population growth and economic development, especially in Third World countries, are having a more significant and direct impact on global natural resources than global climate change. If you will, we humans have exceeded the "carrying capacity" of our global world. This probably started to occur sometime between the 1600's to 1800's, and was mirrored by the geometric progression of medical, industrial and agricultural development. Exceeding our carrying capacity is the real problem we

need to solve. The money that the U.S. and other world governments will "throw" at the global warming/climate change crisis (??) will not solve the problem. This money needs to be thrown at the more immediate problems, i.e., the things that we may actually be able to fix. If you have ever seen the amount of money (mostly taxpayer's) thrown at solving the so-called problem of coastal erosion (a natural process) to protect the houses or commercial enterprises of wealth people, you know that it is a waste of money. Beach renourishment is only a temporary fix, up to and until the next big coastal storm erodes all the sand away. You cannot "fix" a natural process with process. Engineers have being trying to do it for centuries with only limited success. Trying to "fix" global climate would be like renourishing a beach (a temporary stop-gap measure), or like trying to fix the next ice age. We are like the wooly mammoth ... big, powerful, strong, but lumbering and slow to adapt. We need to "adapt" to change and not try to "fix" the inevitable change to our natural world. The NWRS needs to adapt or go the way of the mammoth!

- A53: I view many of the scenarios you presented as short term vs long term. I think in the short term we may have to use some of each approach through use of adaptive management techniques and monitoring. In other words don't give up to quick, maintain options and see what we as a society can do to slow or change our impacts to the environment.
- A54: We cannot afford to 'fight' natural processes, in fact, that is why we have such complex issues facing us today on our lands i.e. making wetlands in xeric habitats, drainage districts to drain swamps etc. The focus of the fish and wildlife service needs to be realigned in an effort to protect and manage habitat that will sustain itself without the massive inputs of energy and money. Currently many of the smaller refuges are forced to invest large sums of time and money to manage habitats for objectives that are not naturally realistic. We need to focus our expenditures on areas that are autonomous so that we are not paying for a losing battle or investing time and money into perpetuity to manage for a static environment. The entire world is extremely dynamic, and the processes that drive the systems on earth are extremely dynamic. Current philosophy held by many if not most of my colleagues is that we should be restoring historic populations and communities , however, I am of the belief that we should focus on what we currently have and what our current potentials are; I am not philosophically tied to the past and do not see how spending the time and $ required to maintain static systems is productive, when we could protect and enhance much more if we were prepared to deal with the dynamic nature of our world.
- A55: The refuge system must become more pro-active in acquiring lands, conservation easements or cooperative agreements that will allow species to respond to climate change. A major factor is also the human impact on the landscape brought about through land use changes that now block corridors, migration routes, gene flow and access to habitats that may become suitable in the future. Were more suitable habitat corridors available, at least some species could use them to successfully accommodate their ranges to new conditions. In

most cases, I think our extremely limited resources are better spend securing a reasonable, scientifically based future rather than fighting a generally losing battle to hold onto the unsupportable past . Where specific conditions allow and corridors are not feasible, transporting individuals to unaccessible but newly suitable habitats may serve the purpose. We may not be able to do much to control climate change, we may be able to do something about human induced land use conversion. Water is already a limiting factor, planning on getting groundwater or other water rights to compensate for loss of local precipitation is not going to happen. Human use will trump wildlife use in the crunch.

- A56: On the scenarios you presented, I was often somewhere in between the alternatives. In some cases we can manage habitats to maintain the current suite of species, but in other cases the proposed fix may be too overwhelming. I'm not sure if we can engineer our way out of this problem. Further, sometimes determining what are the original native species or habitats is difficult on some refuges. Many of the Refuges in my Complex might already be considered artificial or not natural because they were formed by dammed reservoirs. The habitats that are there now were not the same historically. So do we continue to maintain the habitats that were created by man as we are doing now or do we let a more "natural " condition prevail that results from climate change even though climate change is related to human activities. Also some refuges provide only a small portion of the habitat that it takes to maintain some species. And in spite of the scenarios indicating that budgets and public support were equal, we do have to consider the reality of those in the future. Let's face it, the Fish and Wildlife Service is not awash in money and staff and depending on the politics of the country, our budget and the importance of what we do ebbs and flows. Right now we are just trying to keep the refuge system from drowning. And with America becoming more and more urbanized and focused on technology, I start to wonder if in the future many people will really care what happens to wildlife. When I look at the development frenzy that is happening in my area, I really get discouraged. We humans want what we want and we want it now - we want conveniences - we want stuff and lots of it. Preservation of wildlife habitat or open space is generally way down on the list. Just a few thoughts that may or may not be relevant to what your doing.
- A57: I believe we need to change our way of thinking from looking at and managing for historic conditions to considering the potential effects of climate change on wildlife and habitats. We do not fully understand what the changes will be, but we may do more damage (or waste resources) by "fighting" against changes that will occur. We need to enhance our monitoring capabilities so that we can detect when such changes are occurring, conduct research to understand the changes, and adapt (not fight) to climate change. The bigger challenge and responsibility is for human society to minimize and mitigate those anthropogenic factors that are causing climate change to alleviate future changes.

- A58: I did not answer any of the “story questions” since I did not agree much with any of the choices. It is my opinion that we should assume that climate change will occur at some level and manage that level as a natural change. There may be specific cases where the Endangered Species Act, other law, or similar factor would make this choice unfavorable and a more active approach would be needed. In a lot of the cases it will be hard to point to whether climate change or another, totally separate, factor is causing the change. If we just pick 2008 (pick any year) as the baseline and work to hold habitats and species at that level we will expend a large amount of effort, money and goodwill with little chance of success over the long term (e.g. predator or other native species control has little chance of success over the long term) but may work over the short term. We must assume that with climate change we are talking about a century or more not one or two decades. Even if we were provided money in the next 10 years to begin addressing these factors, I doubt that we would be able to sustain the amount of funding needed to maintain these management actions. My guess would be that active management to combat species adaptations to climate change will have unintended consequences that are equally as bad if not worse.
- A59: Intensive management occasionally but not always justified. In scenarios, the more intensive solutions are justified if societal actions suggest the climate perturbations are temporary; build a dike of the flood is temporary or occasional, not permanent and fixed.
- A60: Our National Wildlife Refuges are predominantly marine, uninhabited, and with few anthropogenic disturbances. Coral reefs will likely respond by growing upwards as sea level rises, and low reef islets are expected to erode and reduce habitats for a variety of migratory, endemic, threatened, endangered, and perhaps many non-described species. Our priorities should be to focus on these vulnerable species dependent on land areas for resting, migrating, and nesting, even if it means employing engineering structures to save these species and habitats especially from sea level rise and inundations. However, the coral reef part of these ecosystem is a living feature that will continue to grow upward as sea level rises. In turn, there will be a point where sea levels will rise much more slowly allowing equilibriums to be reached that allows islands and terrestrial habitat to stabilize. While the reefs will survive, endangered and threatened species will require our interventions until stability is restored. Extinction is forever, and preventing it for many tropical terrestrial species should be our primary goal in response to global climate change on our predominantly marine NWR ecosystems.
- A62: For the last section of your survey the majority of my responses are based on what I thought was a probable course of action. If the course of action is too extensive and seems as if it is too unsustainable , I do not believe it is worth it.
- A65: Move the focus eastward when considering the purchase of wetland easements/fee interests in the prairie pothole region as the region becomes drier from west to east.

- A66: I think the scenarios were set up as either or (too few options) with not enough information to make a choice (how much funds are available).
- A:67: I had conflicts with the choices you gave to choose from. They were too simplistic. Rarely in the natural world are the choices so clear cut.
- A:68: Climate change impacts and factors are likely to be highly complex, and it is difficult to answer the either-or alternatives presented here based on the information available. These issues would require much more information to address them adequately, such as what are the other impacts of selecting an alternative (e.g. what will pumping groundwater for wetlands do to the water table?), can another protected area more readily meet the needs of species that would be affected by climate change, etc. Actions would need to be considered based on capabilities at a landscape scale, in coordination with many partners, in order to ensure that we can minimize the negative impacts of climate change as much as possible.
- A7: The intensive one-on-one interviews should help expand greatly on what may often appear as conflicting philosophies on managing climate change issues throughout a very diverse set of refuges in the NWRS (with generally valid and often very different legal mandates).
- A:70: Generally, my thoughts are that the Service should try to correct human caused problems to the best of our ability. Especially when T&E or locally rare species are concerned, we should do our best to minimize those introduced effects to bring back to the natural environment.
- A71: My answers to questions 1 - 7 are not as cut and dry as the options given and many times lie somewhere between the two options. I think that to many Refuge Managers, a lot of management decisions will depend on the larger issue of whether or not we think that humans can reverse Global Warming eventually or will this be a sustained trend for a longer time frame.
- A72: After reading your complete survey, I have decided not at participate. Your 7 stories of conservation issues are vague and probably leading with the given answers. Within the short 100 years the National Wildlife Refuge System has been around, several of these issues have been seen by more knowledgeable folks than myself. And that was just due to climatic change from natural weather patterns. Spotted Owls and Barred Owls has nothing to do with man's impacts climate change on the land. Or from what I have read, it is not climate change, but perhaps other things man has done to the habitat. Similar to the White Goose issue, overpopulation allowed liberal seasons and opening of restrictions that would have made Darling cringe. It is also likely to be helping to drive white geese from many of their historical ranges due to continually hunting pressure. And then the landscape changes they created on the environment are making survival for other species much tougher, whether it be the migrating shorebirds losing mudflats to forage on or mottled ducks (now a species on OMB's Species of Concern List) loss of brood habitat. Yet the issue is not white geese on the historical ranges, but directly connected to the production of grain in Northern Louisiana, Arkansas, and up the flyway. As well as the availability of open water

on deep water reservoirs that remain ice free, which provides a site for birds to roost. Canvasbacks and all waterfowl were faced with the same problem in the dust bowl years and again at least twice since then. If we respond to changes without any understanding whether the condition is a short cycle or long term issue, we can (and have) destroy the very likely thing we are facing. Restoring Prairie is a great example, on the Chenier Plains of Texas & Louisiana, the Chenier Prairie Complex is one of the most endangered ecosystems around. Less than 0.1% remains, yet I can point to unplowed prairie that was destroyed on NWR's within my short time with the USFWS. Why, because prairies were not the primary focus at that time, and a less than holistic thought process was used. The issue whether to levee in specific habitats due to flooding has been addressed by coastal refuges in Louisiana for more than 65 years. In the 1930s, biologists saw the problems with salt water intrusion in coastal marshes and started making plans to construct levees. In the 1950s larges as large as 42 square miles on one refuge was placed behind levees to stop salt water intrusion. This issue was not sea levee rise, but dredging of channels that drained the fresh water head from wetlands and on incoming tides refilled it with water with higher saline contents. Wildfires that are more common and intense, could these be minimized by the more prudent use of prescribe fire to reduce fuel loading, thus making it tough for the intense fires, even in drought conditions, to not have the fuel loads available to make the fires as destructive to the habitat. These and all of the situations are being faced by managers and biologists in the recent past and will continually be faced in the future. It is why we must be thinkers and adaptive. And if we are not, we lose. And wildlife suffers. And this is not even addressing the issue whether the most recent climate change data and links to sunspots is accurate. Or whether some of the trends shown in the 18 months towards changes to a cooler spell are accurate either. Just don't wish to be linked to another dooms day forecast. I face that already each day and that has more to do with lack of funding rather than climate change.

- A76: Your questions are not really reflective about my thoughts on changing climate. Each refuge should be incorporating management techniques that mimic historic events. The misnomer in all of this, especially with prairie and forest systems is that woody encroachment is somehow occurring faster than in the past. I would argue that the natural disturbance patterns are not occurring anymore and this fact actually has more negative impact to our resources than climate change. Start focusing on natural disturbances as management treatments instead of worrying about things that we cannot predict. I often say that our fire program is in a restoration phase instead of maintenance phase, this fact has nothing to do with climate and more to do with mans influence on the natural systems.
- A:77: Yes, the survey does not address the need to provide wildlife corridors for movement of terrestrial and aquatic plants, animals, and natural communities (aquatic and terrestrial) across the landscape in response to climate change.

- A78: Wildlife management is not as cut and dry as portrayed in the above scenarios. Specific management activities will be very site and situationally specific. In many cases there you may opt to utilize a variety of options to address the problems: one solution in one part of the refuge and another in a separate area. And these solutions have to be dynamic and may change as conditions change. Adaptive management techniques will be critical to our success.
- A79: Although I have been with the FWS for only a short time I have been working in Alaska for over twenty years as a Biologist with the FS & NMFS.
- B4: The effects of global climate change are complex and our responses to them need to be adaptive and not reactionary. Since this complexity can be mind-boggling, I would like to see a forum where we can discuss potential measures that, based on experiences with other major disasters such as hurricanes, earthquakes and floods, may be feasible. Given the failure rate and cost, we should not place an emphasis on hard structures.
- B6: The 1980 CCP is out-of-date and doesn't address the current situation surrounding the 2009 CCP effort just starting. A no holds barred "best science" education and outreach program about effects, outcomes, impacts, and human choices that respond to (not just react to) a changing climate is the first best and perhaps only priority. The Service should inform and lead. Construction solutions and active habitat manipulations are quick fix "lies" that do not and will not address the magnitude of changes we and our children's children will live with.
- B7: Can't answer these questions very well unless we know the role an individual refuge plays in conservation of particular species (e.g., the duck question). If there is to be regional or national guidance, there have to be integrated landscape level habitat conservation objectives.
- B11: First, I don't think the change in weather is going to take place within the next few years. I do not have a crystal ball to predict nuclear war or a huge earthquake. All I can do is manage for the species I am responsible for to maintain some genetic material. Managing globally is outside my expertise. What if I picked an area in Africa for nesting turtles and due to political unrest, they slaughtered all the nesting turtles for food. I think we should proceed slowly because climate change will be slow. Who knows, maybe some species will adapt. But again, we as humans believe we can fix or manipulate the earth or we believe we can sit by and let nature take its course at any cost.
- B12: To my way of thinking, global climate change is too long term for temporary fixes - and there have been changes to flora and fauna since the beginning (whenever that was) . To try to preserve the status quo is a loser proposition. I hate to think of extinction of a species (or multitudes of species) but we don't live in a static environment, and short term fixes are for short term problems. So far as the questions, I understand they speak to attitudes regarding climate change - but to be fair, there are many other alternative solutions or combination of solutions available to the scenarios given. They are rather like the question, "would you rather kill your mother or stick a sharp stick in your eye?" If I have to

make a choice, I will - but to quote Hannibal Lector in Silence of the Lambs, "you didn't really think you could dissect me with such a blunt instrument, did you?"

- B13: Although I believe the current rate of global warming to be anthropogenic, I think that the inevitable changes that will occur over the next 50 years should be treated as "natural" adjustments that we should not attempt to mitigate in place. This will end up being such a costly undertaking that it will not be feasible. We must remember that there will be extreme disruptions to human societies and economies that will take precedence over impacts to wildlife. Right or wrong it is a fact. Refuges will become zoos if we attempt to maintain existing wildlife populations and habitats given the expected changes from global warming.
- B15: every refuge is different, managers are different some are extreme tree huggers others are more management oriented. no one is always correct in there management style, some mangers are much more experienced than others.
- B18: Climate change is a natural process that has occurred before and will continue to occur. Surely some of it is exacerbated by man living on earth but there is very little that we can do but adapt to the changes.
- B19: I don't think most of these choices are as concrete as they appear. It depends on other factors, such as what other habitat might be available somewhere and how far away it is. In some cases it might be more important to intervene, at least in the short term until we know more. In others it may be possible to let things move on their own; however, this also depends on what other species they may be impacting. In some cases the advancing species may be in more trouble, and in others the species that is being advanced upon may be worse off. Everyone in this country, especially the lawmakers, should have to take this test and see what difficult decisions will have to be made.
- B23: I feel that public outreach and education regarding climate change is important for the FWS to address and embrace.
- B27: I do not completely agree with all the strategies in the answers I selected. Strategies from both answers could also be combined effectively. Very interesting questionnaire. Thank you for the opportunity to participate.
- B29: I think it is a fantasy to think that the FWS can adequately "manage" habitat and wildlife in the face of global climate change. At best they can document changes and predicted changes to demonstrate to the public what will happen/is happening due to climate change. If folks value wildlife and wildlands (and all of the other things that will be compromised by inaction in the face of anthropogenic climate change), then maybe, as a national and global population, we'll do something about it. Of course, that prospect may be as much of a pipe-dream as the Service's belief that they can effectively deal with the consequences of it on their refuges.
- B32: Ozark Plateau National Wildlife Refuge was established to protect federally listed endangered and threatened cave species (Ozark big-eared bat, gray bat, and Ozark cavefish). When the refuge was established in 1986 the endangered gray bats arrived at their summer maternity caves in April and left in October to

migrate back to their winter hibernacula in northern Arkansas and southern Missouri. But now they are arriving in March and leaving in November.

- B37: We have to recognize that the global changes will take place over a period of time and each of the above scenarios will have transitional periods in which both scenarios would apply until the ultimate hinge point when there should be a shift to my selected alternative. We can't overnight abandon the changes. We will need to transition into the new scenario.
- B39: We need to be addressing the problem related to climate change way beyond the refuge boundary. We need to push for changes in our society that are going to reduce the degree of or reverse climate change.
- B40: For some of the questions, I responded to combat climate change and for others, I decided to adapt to it. Currently, we are trying to combat beach erosion with beach renourishment because we believe there are man-made forces involved (dredging of a nearby channel may be accelerating beach erosion). I believe if you are combating climate change, you would have to evaluate how that is working for you and if it's not working, then you would have to change your management scheme and adapt it to the climate change.
- B41: I am torn between the ideal and what I feel is practical/doable. I realize my responses are often contradictory. I think that we cannot hold back the sea level, so we must manage in those cases to adapt. I am less likely to "give in" when I feel there is some hope of managing for the current status.
- B44: I had a very hard time with these scenarios and was unhappy answering but I did....so hard to answer as right answer depends on much more than articulated here.
- B46: If the phenomenon of climate change is real we must address it in some manner or else it will make everything else we do irrelevant. If the phenomenon of climate change is real it will roll over our feeble attempts to fight it like some juggernaut (hence my preferred response to the above scenarios being to expand and adapt our management system). The key to potential success with the "expand and adapt" response will be to implement interim "holding" actions until we have implemented processes to allow the best trust resources response into expanded refuge operational areas, including non-public lands. In my opinion, there is not enough money to maintain the status quo on refuges in the face of sea level rise and biome shifts -- most public funds will be sucked up by projects trying to protect human infrastructure. Thus, we must devise a system of managing our trust resources that will be, at some point in the near future, self sustaining. Engineered solutions (such as raising coastlines and manipulating plant communities on a mega-landscape scale) to a global phenomenon, while theoretically possible, are impractical. We have to start managing for the future, now.
- B49: How NWRS will respond to threats to individual species will inevitably be related to the public's interest in that species, and economic benefits from that species. It will be easier to take a stance that accepts the effects of climate change on whole ecosystems, or less sexy, popular ecosystems, and harder to

take this stance on charismatic megafauna, or often visited/viewed places like beaches, or other areas important to birding groups and hunting groups.

- B50: I have heard comments from several other biologists that we recognize climate change is an issue and we are being told to "plan" for climate change, but it is often difficult for us to understand the direct effects that we should plan for at our given refuge.
- B52: Dawn - I don't think we adequately included the option to respond differently in the short term vs the long term. I still advocate responding conservatively in the short term, while preparing to respond with climate change in the longer term as uncertainty decreases. John
- B54: Tough questions, management decisions are never easy.
- B57: This is a very somber view of the future of wildlife management. In my 24 years with the Service I have a tough time identifying even one time that we successfully fought the changes caused by climate. We don't have the money, personnel, or support to take on a task as large as global warming.
- C3: Note that Arctic Refuge CCP was completed in 1988. New CCP (2012?) will address climate change. I believe the future of much of the refuge system is imperiled by climate change- it will be nearly impossible for many small refuges in fragmented landscapes or coastal regions to be managed according to their purposes. In contrast, large wilderness refuges embedded in largely intact landscapes (i.e., many Alaska refuges) will allow conservation of functioning, albeit altered, ecosystems.
- C4: It is difficult to make these judgment calls without having more specific in-depth information. Not that I think we should drag our feet when it comes to making decisions, but a panel of experts in the field should be convened to analyze the cost-benefit of the alternatives.
- C6: These are interesting questions that get a very important issue when it comes to management on Refuges in the context of a changing climate. A region-wide dialogue about this is really necessary if we are going to have a unified approach to management. However, in reality things will be handled on a case by case basis, and much decision making is likely to fall to individual Refuge managers.
- C7: Question 23: Uncertain if fire is meant to be considered a factor in landscape change. Some overlap in questions; for example, fire is a driver of landscape change regardless of climate change effects. Pretty hard to ignore probable chances of success/scales of potential mitigation in scenario questions.
- C9: I find it depressing that we act as if these changes are already a done deal. Why aren't we as an agency demanding more sustainable practices to forestall or prevent some of these issues?
- C10: As a manager I work with the tools given to me and try to be creative and innovative in finding multiple solutions to any one problem. Sea level rise and climate change present a new variable we must adapt our management strategies to - we can't ignore the change.

- C12: Question 7. I would like to add the caveat that additional actions should be considered on a case by case basis (i.e. what's the population status off the refuge).
- C13: Of course, but the bottom line is "Nature bats last", (and for better or worse, humanity is part of nature). The sooner we learn that, the better off we all will be.
- C15: Management actions to conserve biodiversity need to be coordinated at a much larger scale than individual refuge units. Direction and guidance needs to be developed at the highest levels of government.
- C16: The seven stories were very difficult. If given a quantity of time to ponder as well as much discussion from experts I may change some or all of my answers.
- C18: Fasten your seat belts - it's going to be a bumpy ride. We don't have enough funding or staff to manage refuge habitats now, much less in a future state of increased instability.
- C22: The task of managing effectively for wildlife/habitat due to human induced factors is difficult at best even without considering the added impacts of human influenced global climate change. Our future management goals and objectives need to be practicable in order to be achievable and focus on the big picture rather than the small to have long term measurable benefits.
- C26: We have not experienced a climate change that is without question outside of what could be normal weather patterns. Although we see some indications of modified weather patterns and associated ecological response, my management activities have remained focused on providing quality habitat that resembles historic conditions and hope that wildlife populations can adjust. I am open to adjusting our management philosophy in response to climate change, but have not found that to be necessary at this point.
- C28: Service personnel have fought landscape change due to anthropogenic causes such as urbanization, farming practices, market fluctuations, and invasive species for many years in order to manage for the historic. My guess is this survey will reflect that mindset.
- C29: It is my opinion that trying to fight climate change at the local refuge level is a losing biological battle. It must be fought at the National and International levels over a longer period of time (i.e. 25-50 years).
- C31: Regarding CCP questions, we believe that impacts from climate change are 1) not well understood at the regional landscape level and 2) are not likely to have dramatic local impacts within the 15-year life of the plan.
- C34: Climate change is presently being addressed in our CCP at the broader scale of fluxes to the distribution of forest types, primarily. We also have conducted some landscape-scale dendrochronology (up to 350 years bp) research aimed at answering fire ecology/mixed-pine forest restoration questions and this research is in manuscript review stage.
- C42: I think in all of the "stories" above, there would have to be an allowing of new species to come in species to go locally extinct- management at any

particular time might include elements to support both old and new species. Good questions to get us thinking about what we will really do.

- C45: We're not going to solve climate change with a band-aid approach to management. We should restore and manage vegetation communities that offer the plasticity to survive in changing climate conditions. Furthermore, the USFWS should educate the public to change our lifestyle. Only through making sacrifices will we reduce greenhouse emissions.
- C48: The Refuge System is too small to deal with changes due to Climate Change. We manage small human impacted postage stamps. Maybe in Alaska or refuges such as Desert NWR will there be habitat available to take in the change that is predicted. The Service needs to model for change at the local, regional, and global level. We manage for endemics and migratory species. The Service should move aggressively to increase funding for additional staff and new lands to "aid " in the conservation of shifting wildlife species and new habitats. Remember, that the Service at this time is not doing its part to assess or reduce its own carbon footprint. If we are to be the model agency for the federal government it will require climate change to be brought into our mission statement. This is a global issue but we must act locally to address the problem, not just talk about the effects of the problem. The science of climate change has not been presented to 80% of our staff. We should educate and train Service employees, janitors to project leaders, about the issue and then change our actions to reduce the problem. We seem to be missing an important step, fixing or reducing the problem, in only discussing the effects and how we can conserve our current mission - wildlife and habitats of today.
- C50: I do not like either choice for #6. But I do not have an additional suggestion. It is ultimately very frustrating that this issue is not more important to the government and the public as it is the biggest challenge facing humanity in recent times. I agree that the Refuge System will have many challenges based on Climate Change but we are severely limited to do anything about it or its consequences - other than monitor the changes - because we do not have appropriate budgets for projects that can mitigate the changes that are coming. We will be forced to just react. The refuge system is generally reactive and not proactive in many of these management issues.
- C53: Your questions on the CCPs should include a completion date or time frame boundaries. Our CCP was completed in 1987, and climate change was not a major issue at that time. Nor was there a vision statement included. We are preparing to do an update in the next few of years.
- C62: Climate Change is a huge issue globally. Depending what happens in the near-future to address CC, my response to resource issues would change significantly. If CC continues to be exacerbated without global corrective changes, many of the resource issues you ask will be moot in my opinion, as global problems will overwhelm the planet's ability to deal with anything but the essentials.

- C63: Changing climate is likely an inevitable process, whether that change is accelerated by humans or not, so our management philosophy should be flexible enough to allow plant and animal populations to adjust to these changes. This is why it is so important to maintain those plants and animals that occur at the edge of a species range, as these are the ones that will likely allow the species to survive shifts in climate. For species that already have constricted ranges and population size, the best course of action is probably reflected in the desert bighorn and Arctic fox examples above - identify refugia where these animals can survive, and perhaps translocate them to these habitats if natural corridors do not exist, or if refugia are outside of the movement range for the species. It seems to me that our (human) attempts to maintain environments and animal populations at a constant level have usually failed. It is interesting when reading about hurricanes or wildfires in the media, as words like "devastated" or "destroyed" are often used to describe the aftermath of these events on the environment. These events have been part of the natural world since before recorded human history, and nature and natural environments have been able to bounce back, albeit often looking different than prior to the storm or fire. The biggest difference that humans have made is that we've reduce the amount of area available for these natural events to occur, such that there are limited refugia for those species adapted to what we've grown used to (e.g. old growth forest). I also have concerns about trying to determine Minimum Viable Population Size for other species - to me this basically says "how little space can we cram wildlife into so that humans can use all the rest". This touches on a very difficult topic, and one that very few have the courage to address. As wildlifers, we often talk about managing populations of plants and animals, but as a society, we should be talking about how to manage our human population. How is it that we can (as a society) say there are too many Canada geese or white-tailed deer in an urban environment, or too many wolves in the Greater Yellowstone Ecosystem, without looking at our own burgeoning population? I guess this turned into quite a rant - I hope that you find it useful (or if nothing else, entertaining).
- C65: It was really tough choosing the scenarios between extinction of rare species and fighting a losing battle to maintain them. Specifically, in Scenario 2, I like the 2nd option better overall, but don't think long term captive breeding is a solution, so, chose option 1 instead. In Scenario 6, it would have been good to have a 3 option of moving the animals and plants to another island that may become suitable.
- C73: We may not have time to focus on climate change. Pahranagat is threatened by urbanization and withdrawal of water resources. These issues may pose a more immediate threat. You may contact me for a follow up interview.
- C74: Refuges cannot be the be all and end all. Climate change goes well beyond what can be done at my level. This must become a national priority, not limited to refuges.
- C78: These hypothetical questions are difficult to answer given the cost and complexity of the situations.